A Stormwater Master Plan For The University of Pennsylvania

Finding Opportunities for Sustainable Stormwater Management

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Penn
University *of* Pennsylvania

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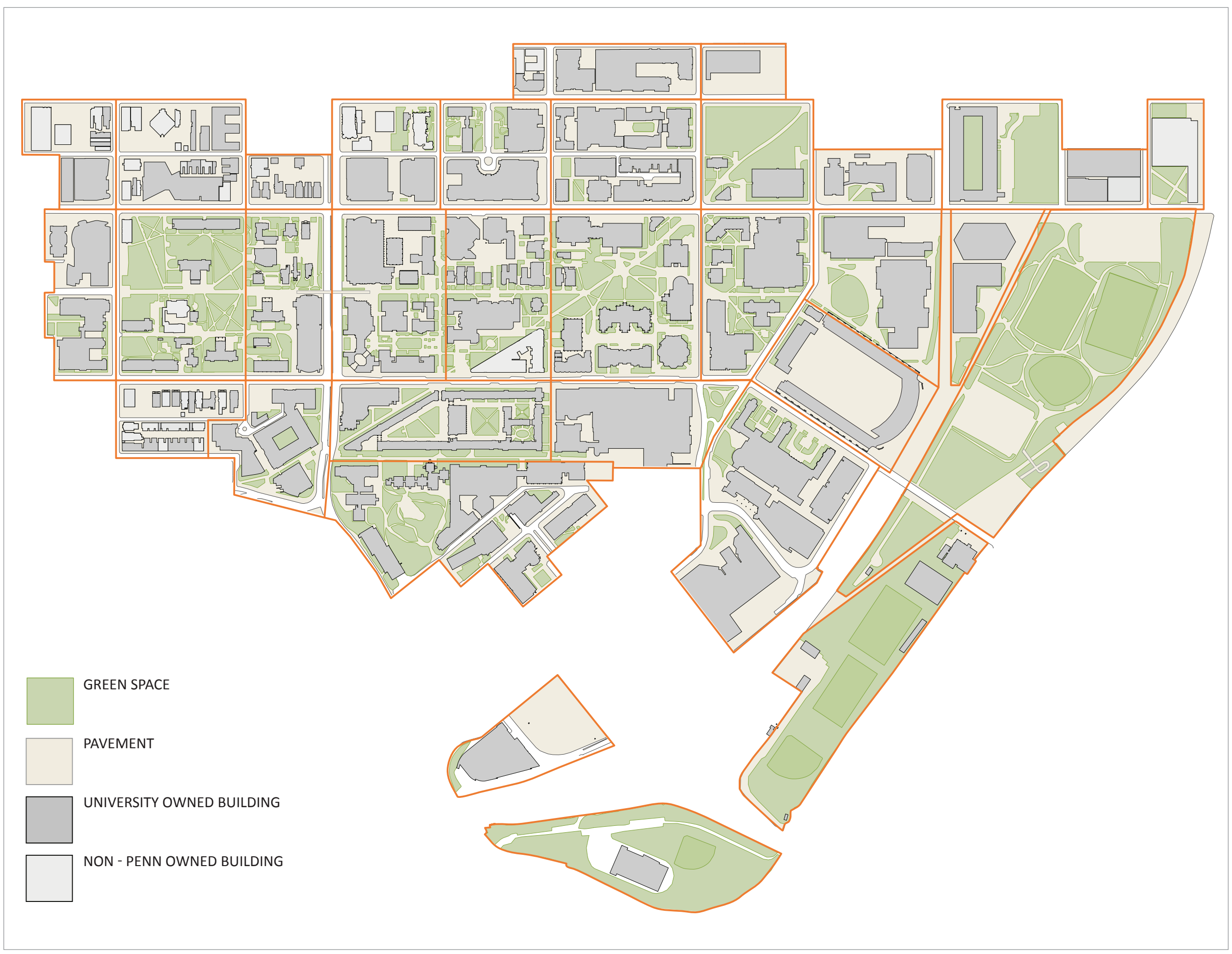
EXECUTIVE SUMMARY

Background

A Stormwater Master Plan for the University of Pennsylvania provides guidance and recommendations for reducing the negative stormwater runoff impacts that are created by the impervious (building and paved) surfaces of the University campus. The purpose of the plan is to aid campus planning by identifying opportunities to incorporate sustainable stormwater management practices into future projects. These opportunities will contribute to the University's goals for increased environmental sustainability, increased green space, and reduced utility costs associated with stormwater runoff.

Stormwater runoff from the vast majority of the campus property and the City streets that cross through the campus is drained via City-owned combined storm/sanitary sewers to Water Pollution Control Plants (WPCP). During rainfall events, the capacity of the WPCPs may be overwhelmed and a combination of polluted stormwater and raw sewage is discharged directly into the tidal portion of the Schuylkill River. Such an event is referred to as a Combined Sewer Overflow (CSO).



Study Area (251.6 acres)

Stormwater runoff from Penn's campus is regulated by the Philadelphia Water Department (PWD). In addition to providing drinking water for the City of Philadelphia, one of PWD's primary goals is to reduce the frequency of Combined Sewer Overflows, for which the City is fined by the Pennsylvania Department of Environmental Protection (PADEP). In 2006, PWD enacted Stormwater Management Regulations that require private and public land development and redevelopment projects to provide stormwater management to meet specific criteria.

In June 2011, PWD signed a Consent Order and Agreement with the PADEP for implementation of their landmark 25-year control plan titled *Green City, Clean Waters*. One of the performance standards included within this plan involves the development of Green Stormwater Infrastructure (GSI). GSI "disconnects" impervious surfaces from the sewer system by directing stormwater runoff through green stormwater management practices (SMPs) such as green roofs, porous pavement, and vegetated bioretention areas. GSI reduces the volume of stormwater runoff from impervious surfaces by utilizing processes such as infiltration, evaporation, transpiration, and reuse. Incorporating these processes within an urbanized environment reduces flow to the combined sewer system, thereby aiding in the reduction of CSOs.

To fund the implementation of the control plan, PWD instituted a monthly parcel-based stormwater fee program in 2009 for all non-residential properties within the City limits. Prior to 2009, properties were charged a sewer fee based on the size of the water meter(s) serving the property. This meter-based method did not account for the impact of a property's impervious area and its contribution to the CSO problem. For example, a high-rise apartment building with a small footprint area generates comparatively little stormwater runoff but has a large water meter to supply the numerous dwelling units, and thus was paying a large sewer fee under the previous system. Conversely, a large commercial parking area with no water meter generates a significant runoff volume, yet paid no sewer fee under the meter-based system.

To provide a more equitable distribution of sewer fees that recognizes the significant impact of impervious surfaces on the CSO problem, PWD instituted the parcel-based fee structure, to be fully phased in by 2014. Under this program, PWD has determined the parcel area and its impervious cover for each property in the City using aerial photography and City tax record information. Fees are assessed at a rate per 500 square feet of impervious area and parcel area. For properties with existing impervious areas, owners can reduce their stormwater fee by voluntarily implementing stormwater management controls that meet PWD requirements and then apply for fee credits. Newly constructed projects that incorporate required stormwater management facilities must also apply for fee credits for the new systems.

Guiding Penn's overall environmental sustainability initiatives, Penn President Dr. Amy Gutmann signed the *American College and University President's Climate Commitment* in 2007. *Penn's Climate Action Plan* adopted in 2009, includes a number of efforts to improve the environmental performance of the physical campus. These initiatives include: the goal to add 20 percent more green space to Penn's campus; install green roofs where possible, adopt a minimum of LEED Silver Certification for new construction projects, and establish protocols for sustainable campus planning. This Stormwater Master Plan will help these initiatives by finding opportunities to reduce the campus' impact on its surrounding environment through the creation of additional green space and construction of sustainable stormwater management practices.

In addition to sending a strong message of sustainability, implementation of the recommendations in the Stormwater Master Plan will:

- *Advance the University's progress in reducing stormwater runoff;*
- *Mitigate on-campus drainage issues;*
- *Provide additional green space;*
- *Provide a cooler campus through reduction of the urban heat island effect;*
- *Reduce the magnitude of Penn's contribution to the City's combined sewer overflow problem;*
- *Reduce the stormwater fees that the University pays to PWD on a monthly basis.*

The Stormwater Master Plan should be viewed as an evolving document. The buildings in the *Penn Connects* and *Penn Connects 2.0* plans are incorporated into the stormwater planning in this Plan. As campus development occurs over time, this Master Plan can be updated to inform subsequent planning efforts, as well as incorporate new green technologies and techniques as they are developed.

Goals of the Stormwater Master Plan

The Stormwater Master Plan assesses the volume of water generated by one inch of stormwater runoff from all impervious surfaces on the campus. The Master Plan only considers runoff generated from private property owned by the University, and does not include runoff generated from the City's streets and/or rights-of-way that cross through the campus.

The use of one inch of runoff as a measure of progress is consistent with PWD's compliance criteria in *Green City, Clean Waters*. The City's compliance with the PADEP agreement will be measured in terms of "greened acres". A greened acre is an acre of impervious cover connected to a combined sewer that is reconfigured to utilize green stormwater infrastructure to manage at least one inch of runoff per storm event.

The goals of the Stormwater Master Plan include:

- *An understanding of the challenges facing the University to provide full compliance with PWD's goal of managing one inch of runoff from all impervious areas;*
- *A detailed analysis and review of existing stormwater management systems on campus;*
- *A review of potential new stormwater management technologies that new construction or retrofit projects can utilize;*
- *A block-by-block analysis of potential stormwater management opportunities, including consideration of future Penn Connects 2.0 projects;*
- *A review of current and pending stormwater legislation that may impact future development on the campus;*

- *A review of current grant or funding opportunities to support development of stormwater management practices;*
- *Initial development of a campus stormwater model to track the construction and removal of impervious area, and to account for the stormwater volume-reducing effects of newly constructed stormwater management practices;*
- *Development of representative details for green stormwater management practices for use by the University and its design consultants;*
- *Development of an Operations and Maintenance Manual for existing stormwater management practices on campus, to provide instructions, recommendations and scheduling for maintaining the various systems, and to facilitate the development of a maintenance log for each practice, as required by PWD.*

The remainder of the Executive Summary includes a summation of the content of each section of the Master Plan. The full sections should be referenced for more detailed discussions of the topics.

Section 2 - Stormwater Runoff from Today's Campus

Stormwater runoff from the vast majority of the campus is not managed by facilities that reduce the rate or volume of runoff. Most campus buildings have their roof downspouts directly connected to the City's combined sewer system via underground pipes. Impervious surfaces at ground level (e.g., parking areas, walkways) typically drain to storm inlets located on campus property or in the City streets that are also directly connected to the public sewer system.

In 2006, the Philadelphia Water Department (PWD) enacted Stormwater Management Regulations as per the Philadelphia Code, Chapter 14-1603.1.6.c.1. These regulations, summarized in Section 2, aim to at least partially restore the natural hydrologic cycle to the City's land by requiring the infiltration of the first inch of runoff from impervious surfaces.

One of the University's primary goals for the Stormwater Master Plan is to assess the feasibility of managing one inch of runoff from all campus impervious surfaces. Another goal of the plan is to seek campus-wide solutions to stormwater management, rather than continue with the current project-by-project approach.

To get an overall understanding of the magnitude of the effort required to manage one inch of runoff from all University impervious areas, all impervious surface areas within the plan's study area were inventoried and the volume of water generated by one inch of runoff from those surfaces was calculated.

The inventory areas (rounded to the nearest 1000 square feet) are as follows:

- *Total Campus Study Area (not including City street rights-of-way): 10,958,000 sf (251.6 acres)*
- *Total Roof Area: 4,051,000 sf (93.0 acres)*
- *Total Ground-Level Impervious Area: 3,787,000 sf (86.9 acres)*
- *Total Impervious Area: 7,838,000 sf (179.9 acres)*

The study area is approximately 72% impervious.

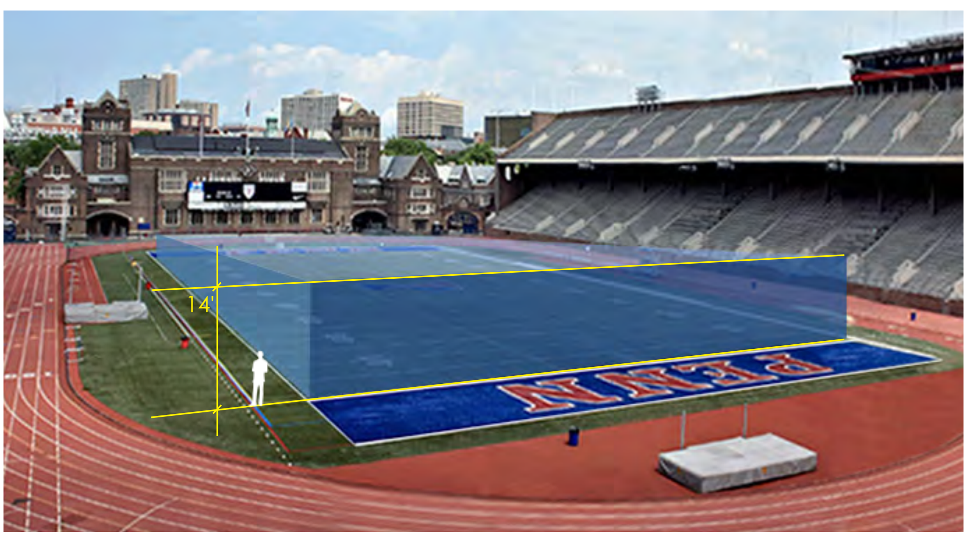
- *One inch of runoff from all campus impervious surfaces generates a stormwater volume of: 653,200 cubic feet, or approximately 4,900,000 gallons of water.*

One potential campus-wide approach to stormwater management, instead of a project-by-project approach, would entail the conveyance of runoff from large areas of the campus to several large regional facilities. Stormwater runoff from a project would not necessarily be detained and/or infiltrated on the project's site, but instead would be drained via pipes to a facility located some distance from the project site.

The efficient storage of large volumes of stormwater runoff requires large areas of land with no buildings. Such large open areas are scarce on the campus, and the few parcels that hold potential for a large regional facility are in consideration for future development. The existing City infrastructure creates additional obstacles to convey stormwater across the City streets that run through the campus.

In light of these physical hurdles as well as need to finance the up-front cost of a regional stormwater facility, the Master Plan assesses the feasibility of shared facilities on a smaller block-by-block basis. The City streets act as the boundaries of drainage areas for each block, and the Plan identifies potential opportunities to manage stormwater within each block. This methodology is in keeping with a basic principle of sustainable stormwater management: rainfall is best managed where it falls, so as to most closely mimic the natural processes that are being disrupted by the existing and proposed construction.

While managing one inch of runoff for the entire campus appears infeasible, it is a relevant metric against which to measure the University's progress toward reducing its contributions to the Combined Sewer Overflow problem.



Example illustrating that one inch of run-off from the study area's impervious area which equals approximately 5 million gallons of water, would flood the football field area inside Franklin Field to a depth of 14 feet.

Section 3 - Stormwater Management on Today's Campus

Since the adoption of the PWD Stormwater Regulations in 2006, Penn has completed (or has under construction) more than a dozen projects that incorporate stormwater management facilities. These projects include green roofs, porous pavement, and bioretention areas, as well as subsurface infiltration/detention systems and water quality management devices.

PROJECT	APPROVAL DATE
• *George Weiss Pavilion*	*February 4, 2009*
• *Music Building*	*February 28, 2009*
• *Cira South Garage (3rd Party Development)*	*March 29, 2009*
• *Class of '62 Walkway (37th Street)*	*May 14, 2009*
• *Woodland Walk*	*July 14, 2009*
• *Penn Park*	*April 29, 2010*
• *Golkin Law School*	*May 7, 2010*
• *Singh Nanotechnology Center*	*February 23, 2011 (under construction)*
• *Locust Walk Reconstruction*	*May 2, 2011*
• *Shoemaker Green*	*July 27, 2011*

A variety of stormwater management practices were utilized in the design of these projects, as noted below:

STORMWATER MANAGEMENT PRACTICE	IMPERVIOUS AREA MANAGED
• *Green Roofs*	*15,511 sf*
• *Porous Pavement*	*49,773 sf +*
• *Bioretention Area*	*140,176 sf +*
• *Subsurface Infiltration*	*13,437 sf*
• *Subsurface Detention*	*467,440 sf*
• *Disconnected Roof*	*3,982 sf*
• *Disconnected Pavement*	*26,777 sf*
• *Tree Credits*	*46,745 sf +*
• *Total Impervious Area Managed*	*763,841 sf (17.5 acres)*

Section 3 includes summaries of the projects and their stormwater management practices, along with site maps for each project showing individual SMP locations. Additional projects in design or construction (or recently constructed) that will incorporate stormwater management practices include Spruce Street Plaza, Hutchinson Gym Renovation, Steinberg-Deitrich Hall Addition, the new College House, Neural-Behavioral Sciences Building, Cira South Chestnut Apartments, and Walnut Street Streetscape Improvements.

Section 4 - Potential Stormwater Management Practices for Future Projects

Stormwater management technology continues to evolve as a result of increased regulatory requirements and a desire to create sustainable solutions that attempt to restore the natural hydrologic cycle by mimicking natural processes such as infiltration and bioretention. Penn has already embraced some of these storm water management practices (SMP's) in the form of green roofs, bio-retention areas, and porous pavements. Section 4 identifies a number of innovative practices which the University and its consultants may want to consider applying as stormwater management strategies for future development and redevelopment projects.

These contemporary practices include utilizing modular green building components, stormwater capture and reuse systems, porous pavement treatments, green streetscapes, and bio-infiltration systems.

Section 5 - Finding Sustainable Stormwater Management Opportunities

Section 5 provides a block-by-block analysis of the campus, identifying potential opportunities for stormwater retrofitting of existing buildings with green roofs; retrofitting of existing paved areas with porous pavements; shared stormwater management facilities; and possible options for future construction of facilities described in the *Penn Connects 2.0* plan. The intent of this distributed approach is to manage rainfall where it falls, rather than concentrating and conveying it via pipes to other locations.

A procedural step-by-step framework is provided for utilizing the block-by-block diagrams in the stormwater planning process. For new construction, these steps include:

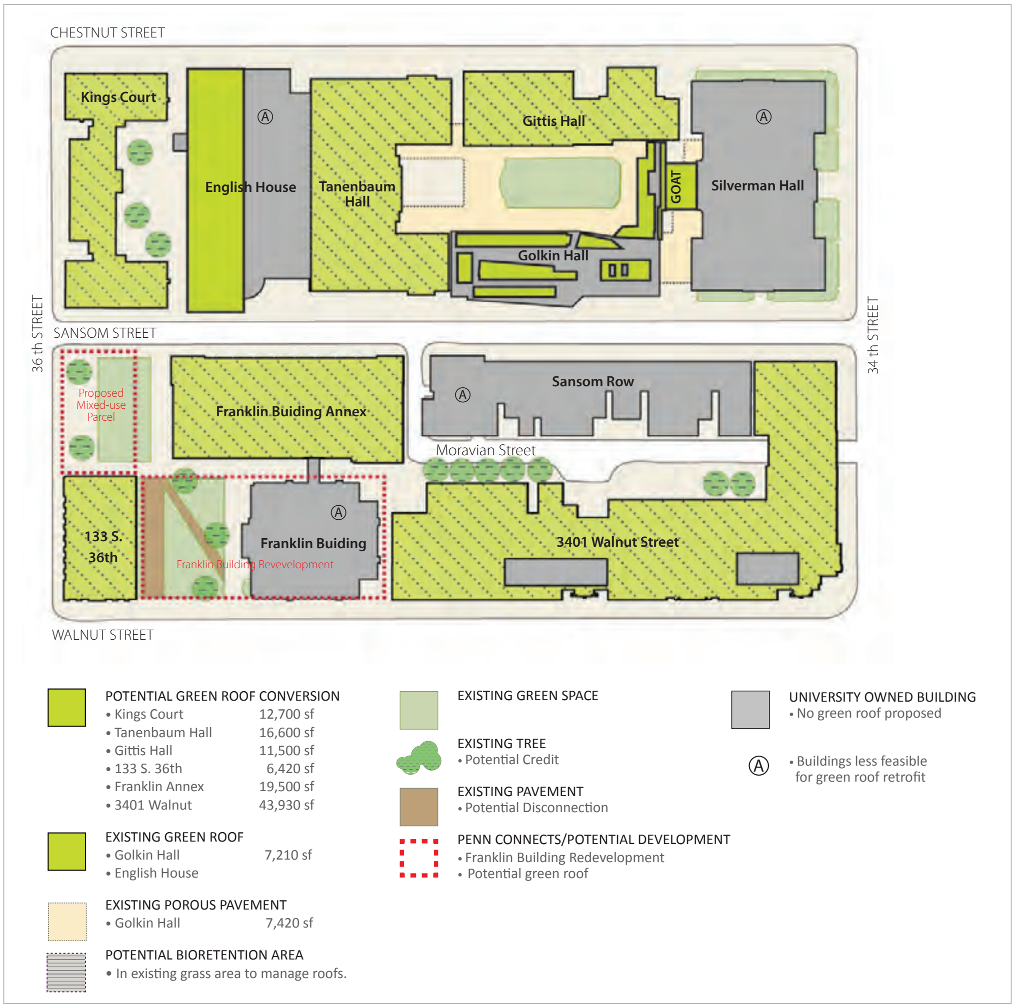
- *Identify project requirements with a conceptual site plan;*
- *Review planned construction on adjoining blocks;*
- *Identify existing utilities in the streets surrounding the proposed construction;*
- *Consider "banking/trading" options (defined in Section 5);*
- *Identify existing utilities within the block of the proposed construction;*
- *Identify shared facility options;*
- *Identify green roof potential for new and existing buildings;*
- *Conduct infiltration testing to determine feasibility of infiltrating stormwater management systems;*
- *Prepare a conceptual stormwater design.*

Additional recommendations are provided for using the block-by-block diagrams in the evaluation of potential retrofit and green streets projects.

Section 6 - Stormwater Management and Construction Costs and PWD Fees

Typical construction costs for the various sustainable stormwater management practices are provided. Ultimately, the PWD Stormwater Regulations will dictate what level of stormwater management is required for a given project. The site design will determine what practices are available to provide the required regulatory compliance. Then site constraints will determine which of those practices will work on the site. These factors will determine the construction costs to be considered when evaluating stormwater management practices for a given project.

The PWD stormwater fee structure is reviewed in detail. The impact of the fee on the return on



Example of typical block-by-block diagram

investment period for stormwater retrofits is described. In some cases, the fee structure does not provide a realistic incentive to invest in green stormwater practices.

A discussion of cost sharing for shared stormwater management facilities is provided. The most feasible approach appears to be the sharing of costs based on the volume of stormwater management for each project connected to a shared system.

Section 7 - Operations and Maintenance Considerations

Under the PWD Stormwater Regulations, property owners must sign Operations and Maintenance (O&M) Agreements stipulating that the owner is responsible for the proper functioning and performance monitoring of the approved stormwater management practices. If the facilities are allowed to deteriorate to the point that they no longer provide their approved design function, the owner could be forced to completely reconstruct the facilities to return the site's stormwater management to compliance with PWD's regulations.

Perhaps the most significant shift in thinking required in the development of green stormwater management is the acceptance that considerable funds must be allocated to the long-term maintenance and monitoring of green stormwater management practices. The systems must be maintained and repaired as needed to ensure that filtration and infiltration continue to perform as intended.

Determining a budget for maintenance is best approached with an understanding that the costs of facility maintenance should be viewed as protecting the investment in the original construction of the stormwater practices as well as protecting the University from liability issues. Additionally, the University's goal of promoting sustainability on campus should support the commitment to diligent maintenance in order to reduce the University's impact on the environment.

The University must evaluate whether to monitor PWD requirements with its internal facilities staff or by contracting the work to a company that specializes in stormwater system maintenance. As part of this Master Plan, cost estimates from outside services were obtained for several University projects. The University will compare these contracted costs to their expenditures using University staff and equipment for the required maintenance. This section also discusses possible changes in the University's landscape maintenance practices which may reduce stormwater facility maintenance requirements.

A separate Operations and Maintenance Manual was prepared as part of this Master Plan. The Manual includes the PWD Operations and Maintenance Agreements for the recently constructed projects, as well as recommended guidelines for maintenance of the various stormwater management practices.

Section 8 - Legislation Issues and Funding Opportunities

Current legislation is discussed, as well as potential impending regulation changes which may impact future development on the Penn campus. Potential sources of funding for stormwater management improvements are also reviewed.

Perhaps the most significant potential change to the current regulations is PWD's consideration of lowering the earth disturbance area threshold that triggers compliance with the stormwater regulations. According to Section 1.2.4.2 of the Long Term Control Plan Update (LTCPU) document, "PWD is considering modifications to the current regulations, including to lower the threshold of disturbance that triggers the regulations for compliance with the regulations from the current level of 15,000 square feet to a level of disturbance of 5,000 square feet." For reference, a typical parking area containing approximately 18 parking spaces with a central two-way drive aisle occupies approximately 5,000 square feet.

The lowering of the earth disturbance threshold to 5,000 square feet would have broader implications for future campus development. With this lower threshold, smaller building additions, parking lot expansions, or pedestrian area restorations could trigger the requirement to comply with the stormwater regulations, and add project costs.

Changes to State and Federal regulations are less well defined. According to the U.S. Environmental Protection Agency's website, "EPA intends to propose a rule to strengthen the national stormwater management program by June 10, 2013 and complete a final action by December 10, 2014." Until EPA provides concise information on what regulatory changes may be coming to Pennsylvania, it is not possible to determine what impacts the changes may have on future campus development.

Potential funding opportunities for the construction of green stormwater management practices are reviewed in this section. The Philadelphia Water Department (PWD) and the Philadelphia Industrial Development Corporation (PIDC) created the Stormwater Management Incentive Program (SMIP) to offer grant assistance to non-residential PWD customers. Funding provided by the program provides incentive for property owners to implement green stormwater management practices that will reduce their monthly PWD stormwater fees. The first round of grant applications ended on March 31, 2012. Based on discussions with PIDC and PWD, the agencies intend to continue the program for several years, depending on its success and the availability of funding.

Section 9 – Recommendations

The Stormwater Master Plan is intended to serve as a planning tool to identify opportunities for increasing sustainability during new campus development or redevelopment projects. Stormwater planning should be incorporated early into the planning process for all new projects.

This section provides recommendations for integrating stormwater planning into the land use planning process, as well as for advancing the University's goal to increase the management of stormwater runoff from currently unmanaged existing sites. The recommendations are more fully discussed in the complete section.

Primary Stormwater Planning Recommendations

1. *Pursue increased stormwater management on a block-by-block approach rather than a campus-wide approach.*
2. *Redevelopment of existing impervious sites on campus should strive to provide a 20 percent reduction in impervious areas compared to pre-development conditions.*
3. *The primary stormwater management goal of all construction projects should be the management of the first one inch of runoff from impervious surfaces for new and retrofit projects.*
4. *The large projects envisioned in the Penn Connects 2.0 plan may provide significant opportunities for attaining meaningful stromwater management practices.*
5. *Consider increasing the storage capacity of stormwater management facilities on new projects to accommodate the future rainleader connection of adjacent existing buildings and runoff from impervious areas which are currently unmanaged.*
6. *Consider stormwater management retrofits of existing buildings and impervious areas as part of the University's renewal and reinvestment program.*
7. *Consider investing in green roofs as a signature feature on Penn's campus. Green roofs often provide cost savings by reducing ground-level stormwater management facilities, increasing*

life cycles of roof membranes, and reducing heating and cooling costs.

8. *Evaluate the feasibility and maintenance costs of installing porous pavements for all new impervious areas as a way to reduce the need for subsurface infiltration/detention systems.*
9. *Continue the current policy to remove surface parking areas by more effective use of perimeter parking structures. Less pavement equals less stormwater runoff.*
10. *Establish a diligent Operations and Maintenance Program to protect the investment in the stormwater management practices already constructed and planned. As with any engineered system, periodic preventive maintenance will always be more cost-effective than delaying maintenance until the system exhibits signs of impending failure.*

Short-term Recommendations (0 to 6 Months)

1. *The University should obtain and evaluate cost proposals for stormwater facility maintenance from several companies specializing in these operations. Using a private company may be cost effective by reducing the training and equipment costs required to implement an internally managed successful O&M program.*
2. *Verify that all applications have been submitted to and approved by PWD for obtaining the stormwater fee credits for the projects constructed since 2006.*
3. *Review the PWD billing information for all University properties to ensure the University is paying the correct fees.*
4. *Continue to meet regularly with PWD to discuss ongoing stormwater planning issues on campus. Additional potential topics of discussion are suggested in the complete Section 9.*

Mid-term Recommendations (6 Months to 5 Years)

1. *Using the block-by-block diagrams in Section 5 as a guide, further evaluate the cost/benefit of green roof retrofits on existing buildings.*
2. *Assess the potential to disconnect existing roof downspouts from a direct connection to the City's combined sewer system and redirect them to new subsurface infiltration/detention facilities.*
3. *As new projects are planned and designed over the next 5 years, the following stormwater practices should be considered as part of the overall stormwater management strategy for each project: capture and reuse of stormwater rainfall, conversion of turf grass areas to bioretention areas and meadow areas, and planting of new trees.*
4. *Gather the construction cost data for the stormwater management practices built as part of the projects constructed since 2006. An analysis of construction costs for these projects may provide valuable cost-benefit information for other projects.*
5. *Consider mapping all non-University utilities located in the City streets to assist with evaluating potential cross-street stormwater transfers and green streets projects.*
6. *Specify the use of double-ring infiltrometers for all infiltration testing. This is the methodology preferred by PWD and PADEP and, should provide the most reliable information for infiltration system design.*

Long-term Recommendations (Beyond 5 Years)

1. *Explore potential "green street" development on campus in conjunction with PWD and the City's Streets Department. Liability issues associated with directing potentially contaminated stormwater runoff from public streets onto the University's private property are discussed in Section 5.*
2. *Promote stormwater research in academic programs. This research could be conducted in conjunction with PWD, PADEP, or other local, state, or federal agencies.*
3. *Consider development of a monitoring program (in partnership with its academic programs) to test installed green stormwater management practices for performance evaluation. This program would undertake more extensive monitoring than that required by PWD. Collected data could be used to evaluate critical design criteria for various stormwater practices. For example, detailed collection and analysis of rainfall data and resultant use of captured rainwater for irrigation water at Penn Park could improve the design of other potential capture/reuse systems on campus.*

Additional guidelines are provided for the further evaluation of potential green roof retrofitting of existing buildings, including structural considerations.

It is anticipated that the information presented in the Stormwater Master Plan will evolve over time as the University's plans for future development unfolds, as new stormwater management technologies and techniques are created, and with the adoption of new stormwater regulations at all levels of government. The Master Plan should be revisited in five years to respond to the University's development and to maximize the use of emerging state-of-the-art design methodologies for sustainable stormwater management.

STORMWATER RUN-OFF FROM TODAY'S CAMPUS

Stormwater runoff from the vast majority of the campus is not managed by facilities that reduce the rate or volume of runoff. In compliance with the City's plumbing code, almost all buildings built before 2006 have their roof downspouts directly connected to the City's combined sewer system via underground pipes. Impervious surfaces at ground level (e.g., parking areas, walkways) typically drain to storm inlets located on campus property or in the City streets that are also directly connected to the public sewer system. These existing conditions rarely promote water quality improvement or quantity reduction of stormwater runoff.

The Hydrologic Cycle

In 2006, the Philadelphia Water Department (PWD) enacted Stormwater Management Regulations as per the Philadelphia Code, Chapter 14-1603.1.6.c.1. These regulations intend to restore the natural hydrologic cycle to the City's land. That cycle begins with rain falling to the ground. In a natural environment, the rain is either intercepted by vegetation or falls on soil where it infiltrates into the ground. In southeastern Pennsylvania, as much as 55 percent of the annual rainfall may be "recycled" to the atmosphere via evapotranspiration by vegetation. The infiltrated water is available for plant uptake or percolates to the groundwater. The infiltrated water also contributes to the base flow of streams and rivers, which helps maintain stream habitat during dry periods. Only after the surface soil layers are fully saturated during larger rain events does surface runoff occur.

In the built environment, impervious surfaces in the form of buildings, roads, parking areas, and walkways interrupt the natural hydrologic cycle by preventing the infiltration of rainwater into the soil and by reducing the amount of vegetation available for interception and uptake. Rainwater quickly flows across impervious surfaces which can cause erosion, siltation, and pollution as soil particles and chemicals deposited on the ground surface (e.g., gasoline and oil on paved areas) are suspended and conveyed to streams, rivers, and lakes. Flooding may occur in low areas due to high runoff volumes and/or high flow rates that may exceed the capacity of storm sewer systems.

As the City of Philadelphia developed, existing creeks and natural drainageways were redirected into underground sewers beneath the City's streets. Older portions of the City, including the entire Penn campus, were constructed with combined sewer systems, where roof drains, yard drains, and sanitary sewer laterals all connect to the same pipe system. Virtually every street on the Penn campus contains a combined sewer owned and operated by PWD. Downspouts from the vast majority of Penn's buildings and storm inlets in paved and vegetated areas connect directly to the City's combined sewer system without stormwater management facilities to reduce the runoff rate or volume.

PWD's Stormwater Regulations

Land development and redevelopment projects in most areas of the City of Philadelphia, including the Penn campus, that cause greater than 15,000 square feet of earth disturbance are subject to PWD's

Stormwater Management Regulations. There are three components of the Stormwater Regulations: Water Quality, Channel Protection, and Flood Control.

The Water Quality requirement promotes recharge of the groundwater table, reduction of pollution in stormwater runoff, and reduction in CSOs from the City's combined sewer systems. The Water Quality requirement stipulates management of the Water Quality Volume, the first one inch of runoff from Directly Connected Impervious Area (DCIA) within the limits of earth disturbance. DCIA is defined as an impervious surface which is directly connected to the stormwater drainage conveyance system, for example, a paved area draining to a storm inlet that is connected to a pipe that drains to the City sewer system. In addition to mitigating the CSO problem in Philadelphia, the management of the first inch of runoff also captures the "first flush" of every storm event, when rainfall washes deposited pollutants from the land surface and carries them downstream. This first flush represents the stormwater volume with the highest pollutant concentration.

Reduction of DCIA will reduce runoff from a site and thereby reduce the size of required stormwater management systems. Methods of reducing DCIA include replacing impervious surfaces with permeable surfaces and disconnecting impervious surfaces. Permeable pavement surfaces may be created with porous asphalt, an asphalt mix with larger pores that allows runoff to drain through the asphalt and infiltrate into the underlying soil. Walkways may be constructed with porous pavers or with solid pavers separated by wider gravel-filled joints that allow the runoff to drain through to the underlying pavement base and soil. Runoff from impervious roofs and pavement may be directed to a pervious vegetated area to achieve a disconnection credit. In addition, green roofs and porous pavement areas are also considered disconnections. A disconnected area is no longer considered DCIA, and therefore does not require further management to meet the Water Quality Requirement. The Water Quality requirement must be met for remaining DCIA by infiltration of the water quality volume, unless infiltration is found to be infeasible for a particular area. Bioinfiltration systems or subsurface infiltration systems are commonly utilized to meet this requirement. If infiltration is not feasible, requirements differ for sites in separate sewer areas versus those in combined sewer areas. For separate sewer areas, 100% of the water quality volume must be routed through a SMP that provides volume reduction, flow attenuation, and water quality treatment. For combined sewer areas, such as the majority of the Penn campus, 20% of the DCIA must be routed through a volume reducing SMP, such as a green roof or a bioretention area. In addition, the release rate for the water quality volume must not exceed 0.24 cubic feet per second per acre of DCIA, and must be detained for no less than 24 hours and no more than 72 hours.

The Channel Protection requirement specifies the slow release of the 1-year, 24 hour storm event detained from DCIA. This requirement does not apply to projects within the Delaware River or Schuylkill River Watersheds, therefore the University of Pennsylvania campus is currently exempt from this component of the regulations.

The Flood Control requirement reduces the severity of flooding in areas downstream of the development site, and also reduces the frequency and duration of CSOs. Under this component, development projects are required to meet peak runoff rates for post-development conditions that are equal to or less than those from the pre-development conditions for up to the 100-year storm event (8.4 inch rainfall event). Projects that can directly discharge to the Delaware or Schuylkill River main channels without using City infrastructure are not subject to this requirement.

The most significant improvement that can be made to a land development project, in terms of reducing stormwater management requirements, is the reduction of existing pre-development impervious area by 20 percent. Projects that provide this 20% reduction in impervious area are exempt from the Flood Control requirement, thereby eliminating the need for large detention systems and the larger pipes needed to convey the 100-year storm to the systems.

Another incentive offered by PWD is the designation as a Green Project. For redevelopment projects that disconnect 95% or more of the DCIA, PWD provides an expedited Green Project Review from PWD, in which the department will provide a review letter within five business days of submission. Subsequent revised submissions also receive a response within five days. Since 95% or more of the proposed DCIA is disconnected, no further stormwater management is required. An example of a Green Project would be a building with a green roof, whose paved surfaces are constructed of porous pavement. In such a Green Project, a maximum of five percent of the site's hard surfaces can be impervious.

The Challenge of Compliance with the PWD Regulations

An original goal for the Stormwater Master Plan was to assess the feasibility of managing one inch of runoff from all campus impervious surfaces. Another goal of the plan was to seek "campus-wide" solutions to stormwater management, rather than continue with the current "project-by-project" approach.

Because the University is only responsible for stormwater runoff generated by its property not including the City's rights-of-way (and is charged stormwater fees by PWD only for that property), the Stormwater Master Plan currently considers only that private property. The plan does not consider runoff from the City's streets and sidewalks, though could be revised in the future to do so. For example, the University may choose to create "green streets" in conjunction with the City, where runoff from private and public areas is combined and managed in shared stormwater management systems.

To get an overall understanding of the magnitude of the effort required to manage one inch of runoff from all University impervious areas, all impervious surface areas within the plan's study area were inventoried and the volume of water generated by one inch of runoff from those surfaces was calculated. Aerial mapping provided by the University, updated to reflect recent construction projects, was used to determine the total building and ground-level impervious area within the study area.

The inventory areas (rounded to the nearest 1000 square feet) are as follows:

- *Total Campus Study Area*
  (not including City street rights-of-way): 10,958,000 sf (251.6 acres)
- *Total Roof Area: 4,051,000 sf (93.0 acres)*
- *Total Ground-Level Impervious Area: 3,787,000 sf (86.9 acres)*
- *Total Impervious Area: 7,838,000 sf (179.9 acres)*

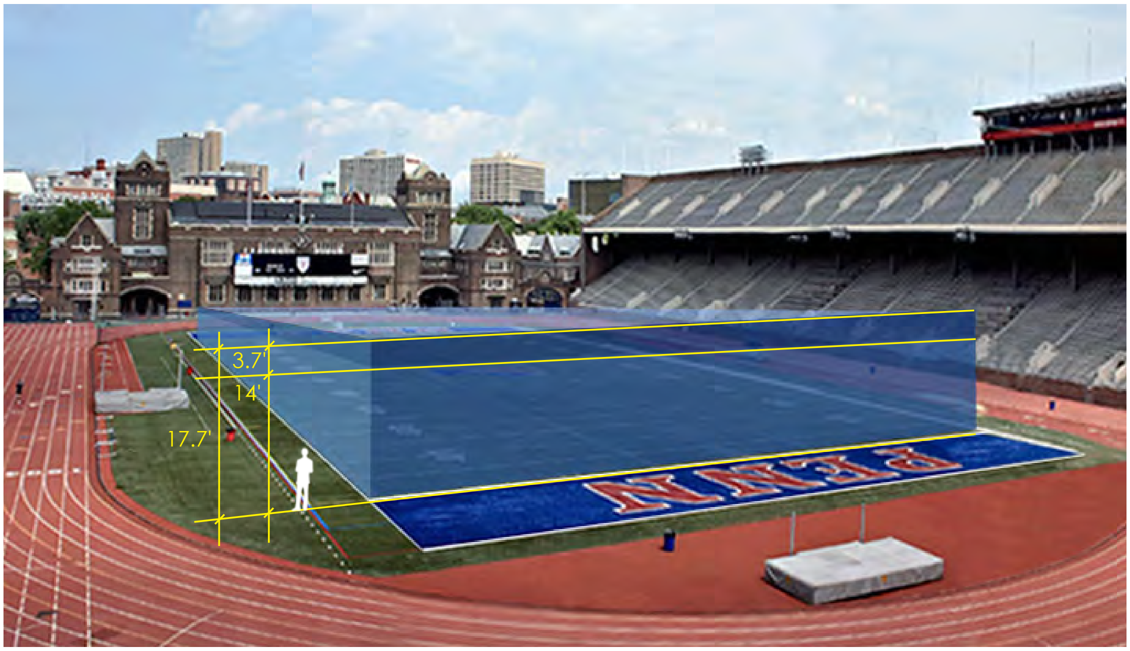
The study area is approximately 72% impervious.

- *One inch of runoff from all campus impervious surfaces generates a stormwater volume of: 653,200 cubic feet, or approximately 4,900,000 gallons of water*

*Note: the areas above include existing green roofs, porous pavement areas, and other areas managed by existing stormwater management facilities.

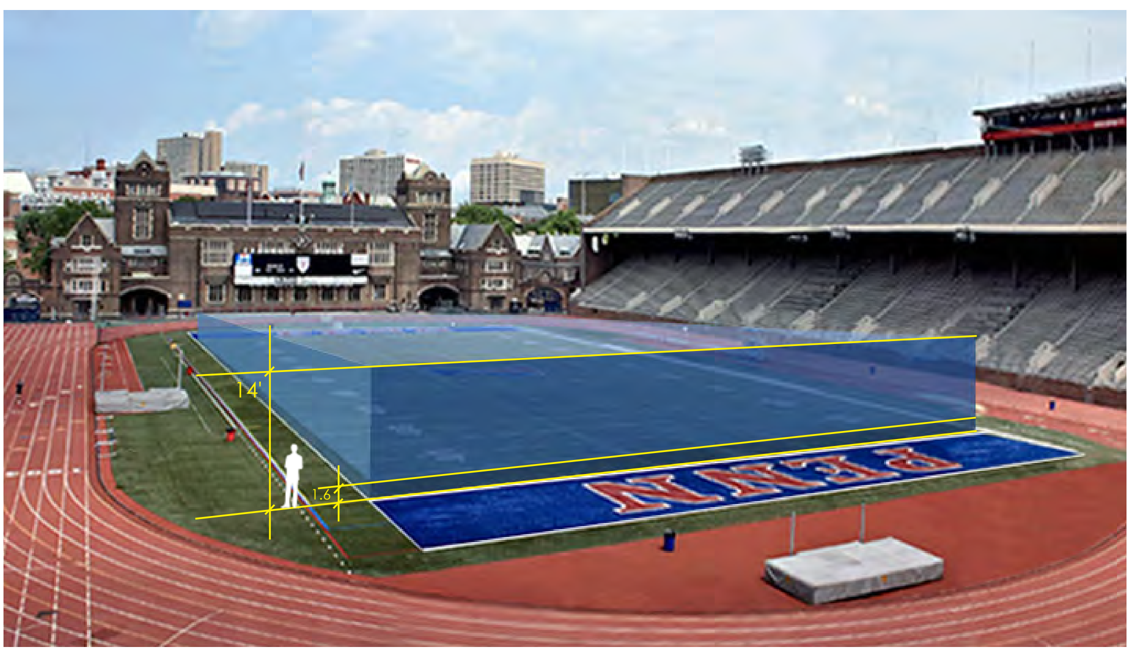
To illustrate the magnitude of this stormwater volume, the following graphics show a representation of the runoff volume "stored" over the football field in Franklin Field stadium and provide simple assessments of where the University's management of one inch of runoff stands today. Additional figures show how increases of different stormwater management practices across campus would impact the University's compliance with PWD's goal of managing one inch of runoff from all impervious surfaces.

- *One inch of run-off from the study area's impervious area would flood the football field area within Franklin Field to a depth of approximatley 14 feet.*



- *If the City's street right-of ways within the study area are included (approximately 50 acres), one inch of run-off would fill an additional 3.7 feet, totalling a depth of 17.7 feet.*

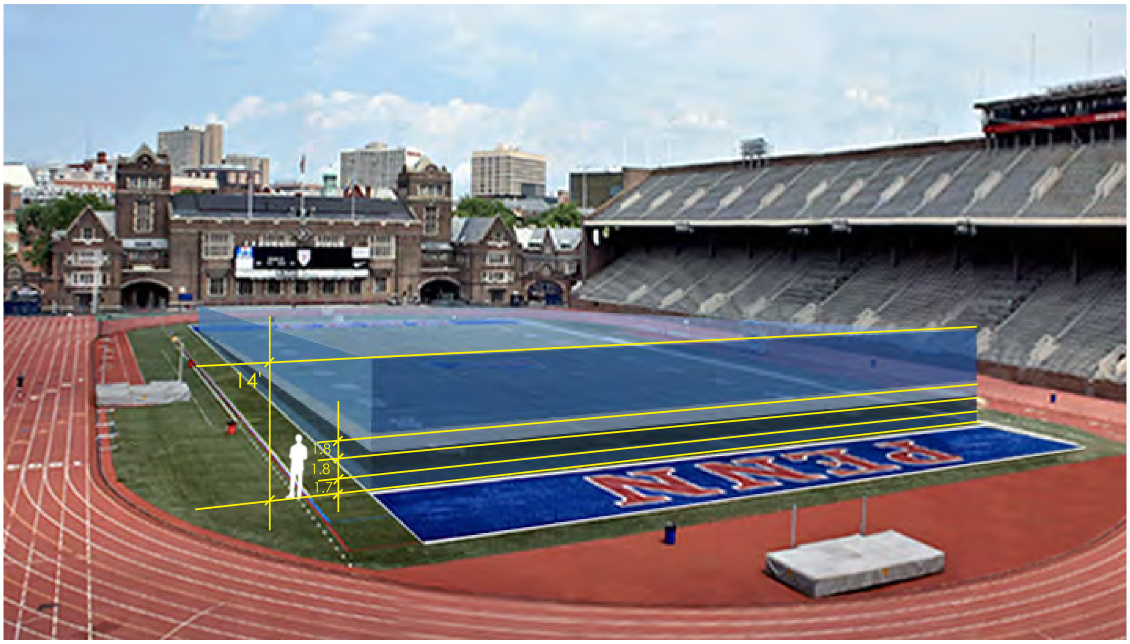
Since 2006, the University has constructed a number of projects that manage the first inch of runoff from impervious surfaces in accordance with PWD's stormwater regulations. These projects are described in Section 3. The figure below illustrates the contribution of these existing projects towards full compliance with the regulations for the University-owned impervious areas.



- *Only 11% (1.6 feet) of the total one inch run-off volume is being managed by existing projects.*

To illustrate the challenge of managing one inch of runoff from all University impervious surfaces, the figure below indicates the level of compliance that would be achieved if:

- *25 % of all campus building roofs were constructed or retrofitted with green roofs (24 acres of green roofs out of 97 total roof acres),*
- *25 % of all campus building roofs were managed by infiltration/detention systems at ground level (an additional 24 acres of managed roofs out of 97 total roof acres),*
  &
- *25 % of all ground level impervious area was managed by infiltration/detention systems (22 acres of managed ground-level impervious area out of 88 acres of total ground-level impervious area).*



- *Approximately 13% (1.8 feet) of the total one inch run-off volume would be managed if 25% of all building roofs were green roofs.*
- *Approximately 13% (1.8 feet) of the total one inch run-off volume would be managed if 25% of all building roofs were managed by ground-level SMPs.*
- *Approximately 12% (1.7 feet) of the total one inch run-off volume would be managed if 25% of all ground-level impervious areas was managed by SMPs.*
- *If all three of these practices were achieved, together only 38% of the University's one inch run-off volume would be managed.*

There are two major challenges to managing one inch of runoff from all the University's impervious surfaces with PWD’s regulations for the entire campus:

1. *The construction of and the significant level of investment required to achieve the improvements represented on the preceding page would result in less than 40% compliance with the regulations.*
2. *A "campus-wide" approach to stormwater management, instead of a "project-by-project" approach is improbable, as discussed below.*

Additional challenges are described below.

A Sustainable Approach to Stormwater Management

A campus-wide approach to stormwater management, instead of a project-by-project approach, would entail the conveyance of runoff from large areas of the campus to several large "regional" facilities. Stormwater runoff from a project would not necessarily be detained and/or infiltrated on the project’s site, but instead would be drained via pipes to a facility located some distance from the project site. There are several obstacles that make a campus-wide approach to stormwater management physically impractical and cost-prohibitive.

The efficient storage of large volumes of stormwater runoff requires large areas of land with no buildings. Such large open areas are scarce on the campus, and the few parcels that hold potential for a large regional facility are in consideration for future development.

Even if large areas of open ground were available, the existing City infrastructure creates obstacles to convey stormwater across the City streets that run through the campus. Numerous public utilities (water, sewer, gas, electric, telephone) of varied sizes and at varied depths are located within the City street rights-of-way. These present significant obstacles to transporting stormwater from one side of a street to a regional stormwater management facility on the opposite side of the street. A storm sewer, flowing by gravity, would be required to convey the runoff across the street, and existing utilities may need to be relocated to eliminate interference with the proposed cross-street sewer. Such construction would also require traffic interruptions and costly pavement restoration.

There may be locations on campus where such "cross-block" transfer of stormwater is feasible, but the scope of this plan does not include analysis of all of the existing City infrastructure within the streets on campus.

Instead, in addition to identifying potential SMPs for individual buildings and paved areas, this plan assesses the feasibility of shared stormwater management facilities on a block-by-block basis. The City streets act as the boundaries of drainage areas for each block, and the plan identifies potential opportunities to manage stormwater within each block.

This methodology is in keeping with a basic principle of sustainable stormwater management: rainfall is best managed where it falls, so as to most closely mimic the natural processes that are being disrupted by the built environment. Ideally, a portion of the rainfall will be infiltrated. Another portion will be taken up by planting and evapotranspiration. The remaining rainfall should be captured and slowly released from the site so as to minimize downstream impacts and, in the case of Philadelphia, reduce the frequency and magnitude of Combined Sewer Overflows (CSO).

Future iterations of this plan may explore cross-block stormwater transfers, including linkages of stormwater management practices such as cisterns capturing roof runoff from multiple buildings or underground infiltration/detention systems managing runoff from multiple parking areas and buildings.

While managing one inch of runoff for the entire campus appears infeasible, it is a relevant metric against which to measure the University's progress toward reducing its contribution to the Combined Sewer Overflow problem.

The following sections of the master plan review the recently-constructed projects that include stormwater management practices and that have set the University on the path toward managing one inch of runoff from all impervious surfaces. After that review, potential new stormwater management technologies and techniques are discussed. Then, a block-by-block analysis of the campus is provided to aid in identifying potential stormwater retrofit projects as well as localized shared stormwater facilities that could be constructed when new construction takes place. That information can be used in conjunction with the *Penn Connects 2.0* plan to lead the University toward increased stormwater management sustainability.

STORMWATER MANAGEMENT ON TODAY'S CAMPUS

Since the adoption of the PWD stormwater regulations in 2006, Penn has completed (or has under construction) more than a dozen projects that incorporate stormwater management facilities. These projects include green roofs, porous pavement, and bioretention areas, as well as subsurface infiltration/detention systems and water quality management devices. Some of the projects also received credit from PWD for pavement disconnections and tree credits.

Since 2006, Penn has been subject to compliance review and approval from PWD's Stormwater Plan Review Group. The following projects have gone through this review and approval process:

PROJECT	APPROVAL DATE
• *George Weiss Pavilion*	*February 4, 2009*
• *Music Building*	*February 28, 2009*
• *Cira South Garage*	*March 29, 2009*
• *Class of '62 Walkway*	*May 14, 2009*
• *Woodland Walk*	*July 14, 2009*
• *Penn Park*	*April 29, 2010*
• *Golkin Law School*	*May 7, 2010*
• *Singh Nanotechnology Center*	*February 23, 2011*
• *Locust Walk Reconstruction*	*May 2, 2011*
• *Shoemaker Green*	*July 27, 2011*

(Note: A number of additional projects were initiated during the preparation of this plan.)

A variety of stormwater management practices were utilized in the design of these projects, as noted below:

STORMWATER MANAGEMENT PRACTICE	IMPERVIOUS AREA MANAGED
• *Green Roofs*	*15,511 sf*
• *Porous Pavement*	*49,773 sf*
• *Bioretention Area*	*140,176 sf*
• *Subsurface Infiltration*	*13,437 sf*
• *Subsurface Detention*	*467,440 sf*
• *Disconnected Roof*	*3,982 sf*
• *Disconnected Pavement*	*26,777 sf*
• *Tree Credits*	*46,745 sf*
• *Total Impervious Area Managed*	*763,841 sf (17.5 acres)*

The following pages include summaries of the projects and their stormwater management practices, along with site maps for each project showing individual SMP locations. The summaries were compiled using available information from the University of Pennsylvania and PWD. The accuracy of this information has not been verified with as-built conditions.

Existing Stormwater Projects

1. George Weiss Pavilion
2. Music Building
3. Cira South Garage
4. Class of '62 Walk
5. Woodland Walk
6. Penn Park
7. Golkin Law School
8. Singh Nanotechnology Center
9. Locust Walk
10. Shoemaker Green

George Weiss Pavilion

200 South 32nd Street

Approved - February 4, 2009

Porous pavements at Weiss Pavilion

Project Description

The George Weiss Pavilion project is located east of 33rd Street, within the northern arcade of Franklin Field and involved 0.78 acres of earth disturbance. The project included the construction of an addition within the existing Franklin Field footprint and the removal of the impervious driveway, parking area, and sidewalk. The removed areas were replaced with porous pavement, consisting of concrete pavers and porous asphalt. Inlets were added for drainage improvement, which tie into the combined sewer within the driveway. This section of driveway is included within the City's Utility Right-of-Way; however the University owns this section of the driveway and is responsible for operation and maintenance of the surface improvements.

Stormwater Management Description

The project decreased impervious coverage by more than 20% from pre-development conditions; therefore it was only subject to PWD's Water Quality component of the Philadelphia Stormwater Regulations and was exempt from Channel Protection and Flood Control requirements. This decrease in impervious coverage was accomplished by the construction of areas of porous pavement. Since approximately 95% of the proposed surface is considered disconnected, stormwater management practices were not required.

Location map - Weiss Pavilion

Inlets have 15-inch sumps and cast iron traps. The porous asphalt is approximately 11,650 square feet in area and consists of a 4-inch surface course over stone, underlain by geotextile fabric. In order to maintain a level bottom, the stone depth varies from 8-18 inches depending on the slope of the surface. Permeable pavers are utilized in approximately 15,320 square feet in area. The pavers are Pine Hall concrete pavers with ¼ inch joint openings filled with aggregate. There is 9-12 inches of stone below the pavers, underlain by geotextile fabric.

- *Porous Pavement: 27,000 sf*
- *Total Impervious area (managed or disconnected): 27,000 sf*
- *Volume of runoff managed: 2247 cubic feet*

Porous pavements at Weiss Pavilion and Shoemaker Green

Music Building

200 S. 32nd Street

Approved - February 28, 2009

Lawn with Subsurface Detention Facility

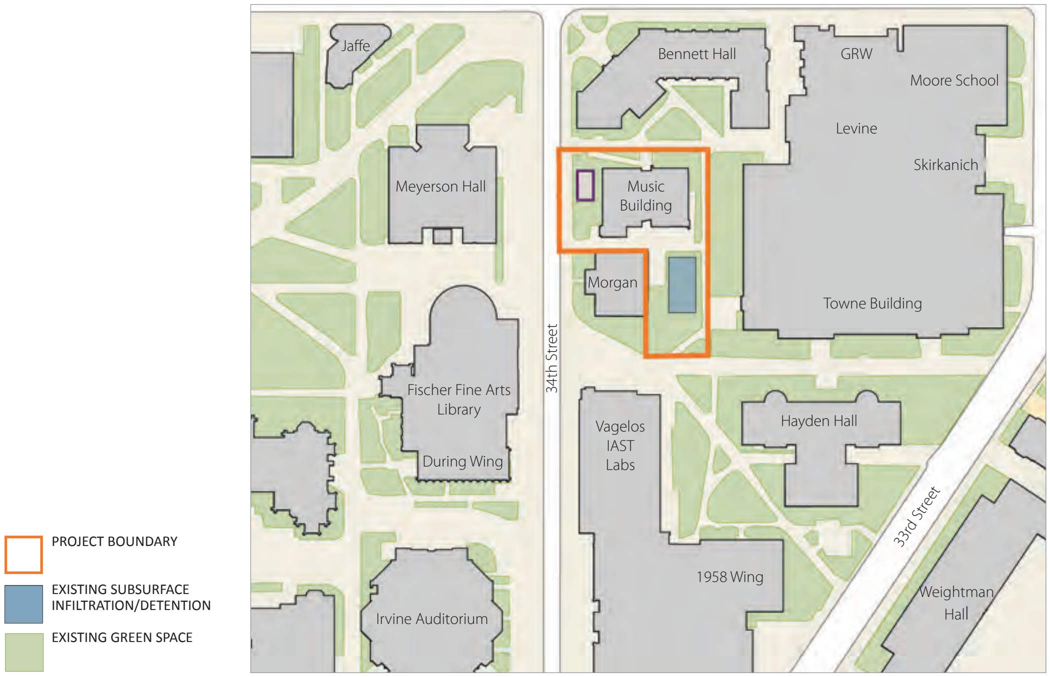
Project Description

The School of Arts and Sciences Music Building Addition and Renovation project is located at the intersection of 34th and Chancellor Streets and involved approximately 2.9 acres of earth disturbance. The project included renovating the existing Music Building and constructing an addition with a 3540 gross square foot footprint. Site improvements also included pedestrian walkways and utility modifications, as well as the demolition of a historic addition to the east of the Music Building and a detached Music Building Annex.

Stormwater Management Description

This project was subject to the Water Quality and Flood Control components of PWD's Stormwater Regulations. Since the project qualifies as redevelopment with earth disturbance less than one (1) acre, it was exempt from Channel Protection requirements. Approximately 247 square feet of concrete sidewalk is considered disconnected since it sheet flows over grass surface area for a sufficient length and slope. Stormwater management is accomplished by a subsurface infiltration system and a bioretention system.

The subsurface infiltration basin is approximately 1,540 square feet in area and is located beneath the landscaped area to the east of the adjacent Morgan Building. The system receives runoff via roof drains from the new addition building and a small portion of the existing Music Building roofs. The management of the portion of the existing building (731 square feet) was considered a trade for impervious ground surface (724 square feet) that was not captured and managed. The basin also receives runoff from pavement and lawn area located east of the Morgan building via inlets and trench



Location map - Music Building

drains. Stormwater enters the infiltration system via a manhole located just outside the northeast corner of the infiltration bed footprint. The manhole includes a 3-foot deep sump to allow for the settling of debris and sediment prior to runoff entering the infiltration system. The basin consists of six 24-inch diameter perforated corrugated metal pipes, connected by a header pipe. The pipes are encased in a 4-foot depth of stone that is wrapped in geotextile fabric. A 6-inch diameter cleanout extends from the end of each pipe to the surface. The outlet structure connects to the system via a 15-inch solid wall pipe and consists of a concrete box with a 1/4-inch thick steel weir plate, approximately 5 feet high from the bottom of the structure. Access to the interior of the outlet structure is provided by a manhole opening. The outlet pipe from the structure connects to the existing combined sewer in Chancellor Street.

The bioretention system is approximately 200 square feet in area and is located to the west of the Music Building, along 34th Street. This system manages a portion of the walkway pavement between the Music and Morgan buildings. Runoff from this area drains to the system via overland flow. The bottom of the bioretention system is lined with geotextile fabric and includes 2-feet of mulch. The overflow structure consists of a 12-inch square grated drain and is set so that the ponding depth of these systems will be approximately 0.8 feet. The outlet pipe from the structure connects to new piping around the Music Building and ultimately discharges to the existing private sewer in Chancellor Street.

- *Pavement disconnection: 247 sf*
- *Subsurface infiltration management: 6,343 sf (include 731 sf outside Limit of Disturbance)*
- *Bioretention Area: 757 sf*
- *Total Impervious area (managed or disconnected): 7,347 sf*
- *Total Impervious area within project limits that is not managed: 724 sf*
- *Volume of runoff managed: 612 cubic feet*

Cira South Garage

120 S. 30th Street

Approved - March 29, 2009

Top of garage

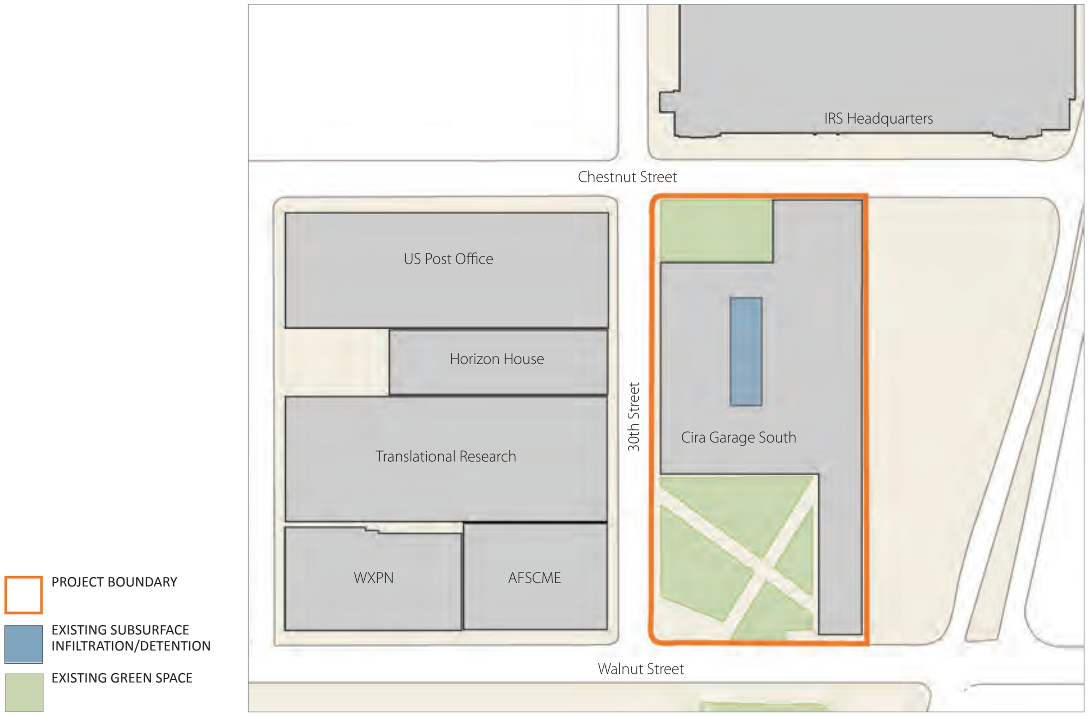
Project Description

The Cira Centre South project is located at 2930 Chestnut Street, running the length of the block on 30th Street between Chestnut and Walnut Streets. Amtrak rail lines run along the east side of the site. The University is currently leasing this property to Brandywine Cira South LP. Formerly, this property housed the United States Post Office Truck Terminal Annex, which was demolished as part of this project to make way for the construction of a 11-story parking garage and two proposed flanking mixed-use towers. The project involved 1.9 acres of earth disturbance. The footprint of the garage is approximately 40,000 square feet at the lowest three tiers and approximately 53,850 square feet for the upper floors, which overhang an Amtrak rail spur on the east.

Stormwater Management Description

The project in its current state, decreased impervious coverage by more than 20% from pre-development conditions; therefore it was subject to the Water Quality component of PWD's Stormwater Regulations and was exempt from Channel Protection and Flood Control requirements. This was accomplished by removal of impervious surfaces and replacement with pervious areas. Management of DCIA is accomplished by a subsurface detention system.

The subsurface detention system is approximately 1,254 square feet in area and is installed below the concrete floor of the garage. The detention system receives garage roof runoff from the roof drainage system. The basins consists of a concrete box that connects to an outlet structure to detain and slowly release stored water. The outlet structure is a concrete box that contains a steel weir plate with one 3-inch diameter orifice and two 8-inch diameter orifices. The opposite side of the weir plate contains an outlet pipe that connects to an inlet containing a backflow preventer device prior to connecting to



Location map - Cira South Garage

the existing combined sewer located in 30th Street. Access to the interior of the outlet structures is provided by manhole openings on each side of the weir wall.

It is the University's intention to construct a green roof on top of the garage in a future phase of construction.

- *Subsurface detention management: 53,850 sf*
- *Total Impervious area managed or disconnected: 53,850 sf*
- *Volume of runoff managed: 4,488 cubic feet*

Walnut Street development parcel

Class of ‘62 Walk

37th Street

Approved - May 14, 2009

Looking South

Project Description

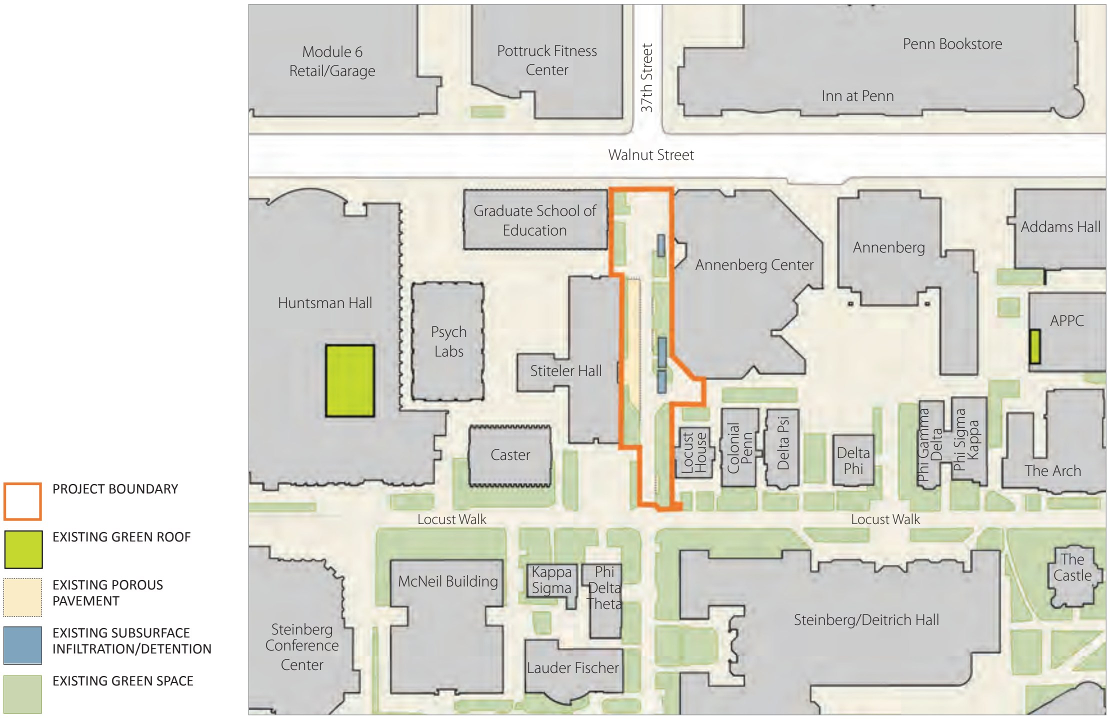
The Class of 62’ Walkway project involved the reconstruction of the 37th Street walkway between Walnut Street and Locust Walk. Impervious driveway and sidewalk areas wereremoved and replaced with porous pavement and landscaping. Inlets were added for drainage improvement, which tie into the combined sewer within the walkway. This section of 37th Street is included within the City’s Utility Right-of-Way; however the University owns this section of the walk and is responsible for operation and maintenance of the surface improvements.

Stormwater Management Description

The project decreased impervious coverage by more than 20% from pre-development conditions; therefore it was subject to the Water Quality component of PWD's Stormwater Regulations and was exempt from Channel Protection and Flood Control requirements. Areas of new impervious pavement were managed by one of two subsurface infiltration basins.

The permeable pavement is located within the walkway. It is approximately 4,200 square feet in area and consists of permeable brick paver units separated by ¼-inch wide joints filled with aggregate. The pavers are underlain by three layers of stone varying in size, for a total thickness of 12-24 inches and lined with a non-woven geotextile fabric.

There are two (2) subsurface infiltration systems, Basins A and B, that are utilized for stormwater management at the site. Runoff from impervious walkway areas is collected by inlets and separately conveyed to one of the two basins. Basin A is located at the driveway entrance to the south of the



Location map - Class of '62 Walk

Annenberg Center and consists of two separate bed areas connected by an 18-inch pipe. The southern bed is approximately 102 square feet in area and the northern bed is approximately 180 square feet. Basin B is approximately 141 square feet in area and is situated further north of Basin A, approximately 100 feet south of Walnut Street, adjacent to the Annenberg Center. The basins consist of two rows of 18-inch diameter perforated plastic pipe connected with manifold pipes and an outlet structure at one end. The pipes are surrounded by a 3-foot depth of stone, encased within a geotextile fabric. The outlet structure for each basin consists of a concrete box with a 6-inch thick concrete weir wall in the center. The intent of the weir wall is to ensure infiltration of the stored water within the basin while allowing larger storm events to overflow the weir to the outlet pipe on the opposite side of the structure. The outlet pipes are protected by trap devices and connect to the private sewer in the walkway. Access to the interior of the outlet structures for maintenance is provided by a manhole.

- *Permeable Pavement: 4,200 sf*
- *Subsurface Infiltration Basin A Management: 4355 sf*
- *Subsurface Infiltration Basin B Management: 2739 sf*
- *Total Impervious area managed or disconnected: 11,294 sf*
- *Volume of runoff managed: 941 cubic feet*

Woodland Walk

3700 Spruce Street

Approved - July 14, 2009

Looking West to 38th Street

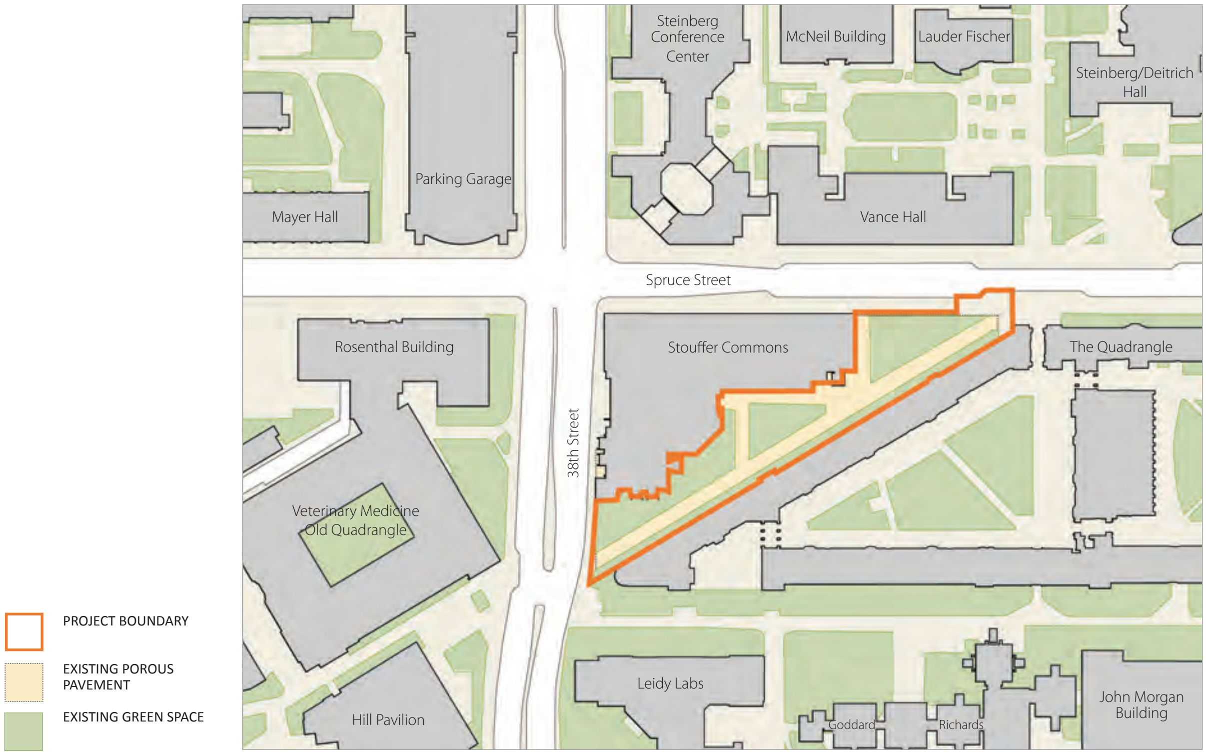
Project Description

The 3700 Block of Woodland Walk project is located between the Quadrangle and Stouffer Commons. The project involved the removal of impervious pavement along the walkway as well as the courtyards to the south and east of Stouffer. These areas were replaced with permeable brick pavement and lawn areas and landscaping. This area of Woodland Walk is included within the Utility Right-of-Way; however the University owns this section of the walk and is responsible for operation and maintenance of the surface improvements.

Stormwater Management Description

The project decreased impervious coverage by more than 20% from pre-development conditions; therefore it was only subject to PWD's Water Quality component of the Philadelphia Stormwater Regulations and was exempt from Channel Protection and Flood Control requirements. Included in this decreased impervious area consideration were lawn and ground cover area, tree credits, and permeable pavement. Since 95% of the project is considered disconnected, no further management was required.

The permeable pavement is located within Woodland Walk and the connecting pathways through the courtyard to the north of the walk. The permeable pavement is approximately 11,183 square feet in area and consists of permeable brick paver units separated by ¼-inch wide joints filled with aggregate.



Location map - 3700 Woodland Walk

The pavers are underlain by three layers of stone varying in size, for a total thickness of 12-24 inches and lined with a non-woven geotextile fabric.

- *Tree Credit: 800 sf*
- *Permeable Pavement: 11,183 sf*
- *Total Impervious area managed or disconnected: 11,983 sf*
- *Volume of runoff managed: 999 cubic feet*

Looking East to Spruce Street

Penn Park

3000 Walnut Street

Approved - April 29, 2010

View Northeast toward Center City Philadelphia

Project Description

Penn Park is located along the eastern edge of campus and is bounded by Amtrak lines to the east, SEPTA lines to the west, Walnut Street to the north, and South Street to the south. This project involved the construction of a park approximately 24-acres in size, including multiple athletic fields, tennis courts, and two parking lots. Improved access to the site was provided by pedestrian bridges extending from elevated landforms to the Walnut Street Bridge, and to the existing Weave and Paley Bridges.

Stormwater Management Description

The drainage area of the site is split between two separate sewersheds. The northern section of the site, including the area to the north of the Hamlin Tennis Center, discharges to the combined sewer in Walnut Street. This portion of the project was required to comply with Water Quality and Flood Control components of the Stormwater Regulations. The southern portion of the site, including the Tennis Center and southward, discharges to the existing City separate stormwater sewer system that discharges directly into the Schuylkill River. This portion of the project was considered a "direct discharge" status, therefore Flood Control was not required, only Water Quality. The entire site was exempt from Channel Protection requirements since it is within the Schuylkill River watershed. Approximately 26,530 square feet of impervious path was considered disconnected, and did not require water quality management per PWD requirements. Infiltration was determined to be infeasible at this site due to existing subsurface conditions. Therefore, the remaining DCIA management is accomplished by a series of non-infiltrating stormwater management practices, including seven (7) bioretention systems, three (3) bioswales, one (1) underground detention system, and two (2) water quality units. The detention basin captures runoff to be used for irrigation during the growing season.

Location map - Penn Park

The northern section of the site consists of the parking lot adjacent to Walnut Street, the two (2) multi-purpose fields south of the parking lot, the softball field, the batting cages, and multiple pedestrian walkways. Stormwater runoff from these areas is collected by a series of underdrains, inlets, and trench drains which convey flows to Bioretention Area #1, Bioretention Swale #1, or the Subsurface Irrigation/Detention Basin for management. Bioretention Area #1 is approximately 16,400 square feet in area and is located to the east of the Walnut Street parking lot. The Bioretention Area #1 system overflow discharges to the City's combined sewer in Lower Walnut Street. Bioretention Swale #1 is approximately 490 square feet in area and is located to the east of the pedestrian path located at the southeast corner of the eastern multi-purpose field. Overflows from Bioretention Swale #1 are conveyed to the Detention Basin. The entire Irrigation/Detention Basin is approximately 15,600 square feet in area and is located between the two multi-purpose fields. The system consists of two separate storage areas- the Irrigation Water Storage Cells and the Underground Detention Basin. The Detention Basin discharges to the existing combined sewer in lower Walnut Street.

The southern portion of the site consists of the Tennis center, the natural turf athletic field south of the Tennis Center, and the future Ropes Course. Stormwater runoff from these areas is collected by a series of underdrains, inlets, and trench drains which convey flows to Bioretention Areas #2-7, Bioretention Swales #2 and #3, or Water Quality Unit #1 or #2. Bioretention Area #2 is approximately 4,150 square feet in area and is located to along the eastern property line, northwest of the batting cages. The inlet overflow for this system discharges to the Irrigation/Detention System, while the underdrains of the system connect to an existing 24-inch separate sewer that runs under the Amtrak tracks. Bioretention Area #3 is approximately 3,279 square feet in area and is located east of the tennis center. The outlet structure for this system ultimately discharges to an existing 24-inch separate sewer that runs under the Amtrak tracks. Bioretention Area #4 is approximately 5,109 square feet in area and is located south of the southeast corner of the tennis center. The outlet structure for this system discharges to an existing 7-foot by 7-foot separate sewer that runs west to east across the site. Bioretention Area 5 is approximately 1,746 square feet in area and is located within an island of Hollenback Parking Lot. The outlet structure for this system ties into an existing 18-inch storm sewer that connects to the 7-foot sewer running west-east through the site. Bioretention Area #6 is approximately 680 square feet in area and is located within a turn-around area, south of the future Ropes Course. The outlet structure for this system discharges to new conveyance piping that ultimately discharges to the 7-foot by 7-foot sewer traversing the site. Bioretention Area #7 is approximately 1,342 square feet in area and is located south of the maintenance building and also discharges to new conveyance piping that ultimately discharges to the 7-foot by 7-foot sewer traversing the site. Bioretention Swale #2 is approximately 679 square feet in area and Bioretention Swale #3 is approximately 991 square feet in area. Both swales overflow to new conveyance piping that ultimately discharges to the 7-foot by 7-foot sewer traversing the site.

Two Water Quality Units were installed. The Water Quality Units are proprietary hydrodynamic separators produced by Contech Construction Products, Inc. These systems function to remove sediments and other pollutants from incoming stormwater flow. As water moves through the system, a separation screen deflects particles which are captured in a storage sump at the bottom of the unit. Water Quality Unit #1 is Contech Model CDS 3035-6-C and Water Quality Unit #2 is Contech Model CDS 3020-6-C.Water Quality Unit #1 is located south of the southeast corner of the tennis center, just north of Bioretention Area #4. Water Quality Unit #2 is located in the Hollenback Parking Lot, just east of Bioretention Area #5.

All bioretention system bottoms are lined with geotextile fabric, which wraps around a 9-inch layer of stone. Four-inch diameter perforated underdrains rest within this stone layer to collect and slowly release the stored water within the system. A two foot layer of planting soil rests above the underdrain system. Cleanouts from the underdrain system are provided for maintenance purposes. A mixture of trees and grasses were planted within the bioretention systems. Each basin connects to an overflow structure, which consists of a concrete box structure with either an inlet grate or manhole lid, and an interior concrete weir wall that contains a 3-inch diameter orifice. The structures contain outlet pipes that are protected by cast iron traps.

Bioretention swales are narrower and longer than the bioretention areas. The cross section of the bioretention swales is similar to that of the bioretention areas, with two exceptions: the bottom stone layer is deeper, at 20-inches for Swale #2 and 3, and the planting soil in Swale #1 consists of 6-inches of sand covered with 6-inches of loam. Each swale connects to an overflow structure, which consists of a

Class of 1976 Plaza

concrete box structure with either an inlet grate or manhole lid, and an interior concrete weir wall with a 3-inch diameter orifice. The structures contain outlet pipes that are protected by cast iron traps.

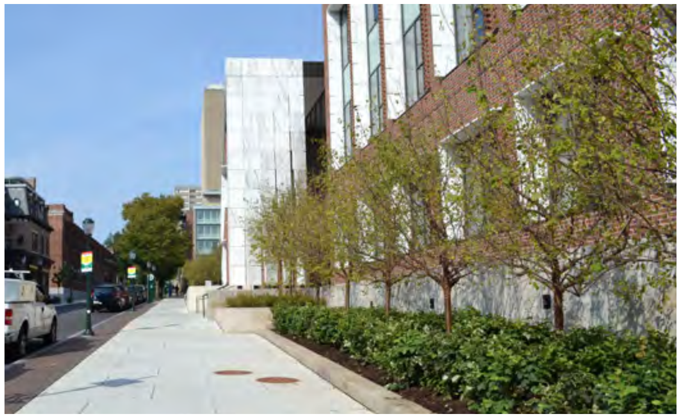
The Irrigation/Detention Basin consists of proprietary tank modules. The modules are wrapped in geotextile and 6-12 inches of stone. The bottom and lower two feet of the Irrigation Storage Cell section has an impermeable liner, to retain the stormwater for irrigation. Due to the proposed intermittent usage of irrigation for this facility, the system was not credited as a water re-use system per PWD standards. However, the remaining storage of the Irrigation Storage Cell section was utilized in conjunction with the Detention Basin to detain and slowly release stormwater runoff to the combined sewer in Walnut Street. There are 6-inch diameter maintenance ports located near the center of each system. Each basin connects to an outlet structure, which consists of a concrete manhole with a concrete weir wall that contains an orifice. The structures contain outlet pipes that are protected by cast iron traps. Access to the interior of the structures is provided by manhole openings. The outlet structure from the Irrigation Storage Cells includes a 6-inch orifice and the structure from the Detention Basin includes a 3-inch and a 7-inch orifice.

- *Pavement disconnections: 26,530 sf*
- *Bioretention Areas:113,206 sf*
- *Bioretention Swales: 2,160 sf*
- *Subsurface Detention: 346,607 sf*
- *Proprietary Water Quality Units: 115,908 sf*
- *Total Impervious area managed or disconnected: 604,411 sf*
- *Volume of runoff managed: 50,368 cubic feet*

Golkin Hall

3501 Sansom Street

Approved - May 7, 200



Sansom Street view

Project Description

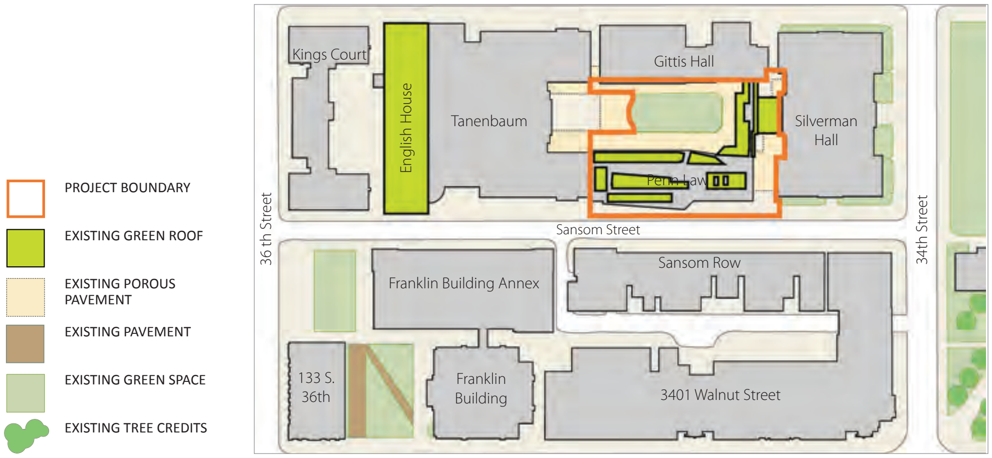
The Golkin Hall project is located at 3501 Sansom Street and involved 0.7 acres of earth disturbance. The project included the demolition of Pepper Hall and construction of the 3-story, Golkin Hall building of 11,630 gross square foot footprint and adjacent driveways, pedestrian walkways, and other associated improvements.

Stormwater Management Description

This project was subject to the Water Quality and Flood Control components of PWD's Stormwater Regulations. Since the project qualifies as redevelopment with earth disturbance less than one (1) acre, it was exempt from Channel Protection requirements. A total of seven (7) new trees were planted along Sansom Street for credit towards a reduction in DCIA. Porous asphalt was utilized in the driveway resurfacing and porous pavers were utilized for the interior pathways within the rear courtyard area.

Portions of the new building include green roof areas, totaling approximately 5,403 square feet of the roof. Portions of the existing "Goat" building, adjacent to the project, were retrofitted with a green roof with an area of approximately 1,808 square feet. The green roofs consist of 3-4 inches of soil media planted with a variety of grasses and sedges. The "Goat" building green roof was considered a trade for new impervious ground cover along the front of the building that was not managed. Areas that are considered disconnected, such as the green roof, porous asphalt, and permeable pavers, do not require water quality management per PWD requirements. Management of DCIA is accomplished by two (2) subsurface detention systems.

The porous asphalt is located within the drive aisle between the Golkin Hall and Silverman Hall. The porous asphalt is approximately 2,755 square feet in area and consists of a 5-inch porous asphalt layer on top of an 8-inch layer of stone and geotextile fabric. There is a 4-inch diameter perforated underdrain within the stone layer of the porous asphalt section to assist with drainage. There is also a surface inlet to collect and convey overflows from the pavement. The porous paver area is approximately 4,669 square feet, is located within the interior courtyard behind the buildings, and is used for the walkway surface. The brick pavers were installed with ¼-inch joints between them that are filled with aggregate. There is an 18-inch layer of stone beneath the pavers. There is a 4-inch diameter perforated underdrain at the east end of the courtyard, resting within a 6-inch sand course at the bottom of the stone layer of the paver section to assist with drainage. There are also a series of trench drains to collect and convey overflows from the pavement.



Location map - Golkin Hall

There are two (2) subsurface detention systems that are utilized for stormwater management at the site. The basins were designed as detention systems after it was determined that infiltration was infeasible at this site due to higher bedrock elevations and the close proximity to building basements and foundations. Drainage from the roof of Golkin Hall is divided and separately conveyed to each of the 2 basins. Basin #1 is approximately 277 square feet in area and is situated beneath a landscaped area to the south of the western 1/3 of the building. Basin #2 is approximately 280 square feet in area and is situated beneath a landscaped area south of the eastern 1/3 of the building. Roof runoff is sent through a Flo-Guard downspout filter, which connect to pipes that convey the runoff separately to each basin. The Flo-Guard unit is a box that is installed within the downspout pipe from a roof to remove non-soluble debris from the runoff. It contains a steel wire basket that is lined with geotextile and can be removed for maintenance.

The basins consist of two rows of 8-inch diameter perforated corrugated metal pipe connected with a manifold pipe, and surrounded by a 3-foot depth of stone, geotextile fabric, and an impermeable liner. There are access cleanouts at the end of each pipe and an observation well at the opposite end for maintenance. Each basin connects to an outlet structure, which consists of a concrete box with a 6-inch thick concrete weir wall in the center. Through the weir wall, a slow release structure is installed that consists of a 1-linear foot section of 1-inch diameter pipe that connects to a 6-inch diameter perforated riser pipe, wrapped in non-woven geotextile. Larger storms will be controlled by the weir structure and overflow to an outlet pipe. Access to the interior of the structures is provided by manhole openings on each side of the weir wall. The outlet pipes from the structures connect to the existing combined sewer in Sansom Street.

- *New Tree Credits: 700 sf*
- *Green Roof: 7,211 sf*
- *Porous pavement: 7,424 sf*
- *Subsurface detention management: 232 sf*
- *Total Impervious area disconnected: 15,335 sf*
- *Total Impervious area managed: 6,225 sf*
- *Volume of runoff disconnected/managed : 1,797 cubic feet*

Singh Nanotechnology Center

3201-59 Walnut Street

Approved - February 23, 2011

Walnut Street view

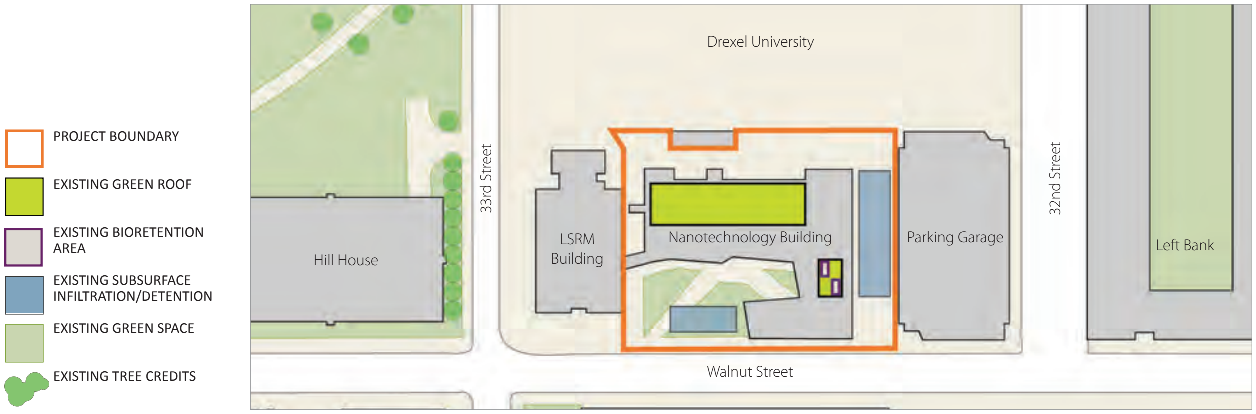
Project Description

The Singh Nanotechnology Center project is located on Walnut Street between the 32nd and 33rd Streets and involves 2.0 acres of earth disturbance. Prior to this project, the area included the Edison Building and a surface parking lot. The project included the construction of the 3-story building with a 32,520 gross square foot footprint, with associated driveways and landscape features.

Stormwater Management Description

The project decreased impervious coverage by more than 20% from pre-development conditions; therefore it was only subject to PWD's Water Quality component of the Philadelphia Stormwater Regulations and was exempt from Channel Protection and Flood Control requirements. Included in this decreased impervious area consideration were green roof areas, lawn and ground cover area, and disconnected roof area. The green roof covers only a portion of the entire roof area. However, some of the impervious roof area drains to the green roof and therefore meets PWD's requirements for disconnection. Areas that are considered disconnected do not require water quality management per PWD requirements. Management of DCIA is accomplished by two (2) subsurface detention systems and a bioretention system on the roof.

The green roof covers approximately 8,300 square feet of the 32,517 square foot roof. Approximately 6,382 square feet of impervious roof area drains to the green roof and is therefore disconnected. The green roof consists of 6-inches of soil media planted with a variety of grasses and sedges. There are also two bioretention areas within the roof system, each approximately 80 square



Location map - Singh Nanotechnology Center

feet. These have a deeper soil media of 2.5 feet and tree plantings. These bioretention systems manage a portion of DCIA from the roof. Runoff from impervious sections of the roof are conveyed and uniformly distributed to the green roof areas via perforated piping.

There are two (2) subsurface detention systems that are utilized for stormwater management at the site. The basins were designed as detention systems after it was determined that infiltration was infeasible at this site due to high groundwater. Basin #1 is approximately 2,073 square feet in area and is situated beneath the driveway to the east of the Nanotechnology building. Basin #2 is approximately 2,858 square feet in area and is situated beneath the triangular landscaped area to the south of the building. Roof and ground surface runoff is collected by a series of roof drains, inlets, area drains, and trench drains, which connect to pipes that convey the runoff separately to each basin. Intermediate sump boxes are provided at the downstream ends of the conveyance piping system in order to settle out debris and sediment prior to entering the detention basins. These units consist of concrete box structures with 15-inch sumps and cast iron traps over the outlet pipes.

The basins consist of manufactured RainTank units wrapped in geotextile, and surrounded by a 3-24 inch layer of stone. RainTank units are open square crates made from 85% recycled polypropylene + 10% proprietary materials. These systems are modular systems and can be assembled to a variety of shapes and heights. There are 12-inch diameter maintenance ports located near the center of each system. Each basin connects to an outlet structure, which consists of a concrete box with a 6-inch thick concrete weir wall that contains a 3-inch diameter orifice. The structures contain outlet pipes that are protected by cast iron traps. Access to the interior of the structures is provided by manhole openings on each side of the weir wall. The outlet pipes from the structures connect to the existing combined sewer in Walnut Street.

- *Green Roof: 8,300 sf*
- *Disconnected Roof: 3,985 sf*
- *Bioretention System management: 2,400 sf*
- *Subsurface Detention management: 49,071 sf*
- *Total Impervious area managed or disconnected: 63,756 sf*
- *Volume of runoff managed: 5,313 cubic feet*

Locust Walk

3600, 3800 and 3900 Blocks of Locust Walk

Approved - May 2, 2011

3900 Block of Locust Walk view West

Project Description

The Locust Walk project consists of the reconstruction of the 3600, 3800 and 3900 blocks of Locust Walk. The project included pavement subbase repair and replacement. This area of Locust Walk, which was formerly Locust Street, is included within the City's Utility Right-of-Way; however the University owns this section of the walk and is responsible for operation and maintenance of the surface improvements. The project included the relocation of existing inlets and the installation of new inlets, replacement of existing storm sewer piping, and the replacement of walkway surface.

Stormwater Management Description

In order to meet PWD's stormwater management requirements, the project utilized existing tree canopy areas for credit. Although it is outside of the project area, PWD allowed the existing trees along the 3600, 3800, and 3900 blocks of Locust Walk to be used toward tree credit for the project. Areas that are considered disconnected do not require management per PWD requirements. The project is disconnecting 95% or more of the post construction impervious area via credits from existing trees. Therefore, this project does not include any SMPs for management beyond inlets and piping for conveyance.

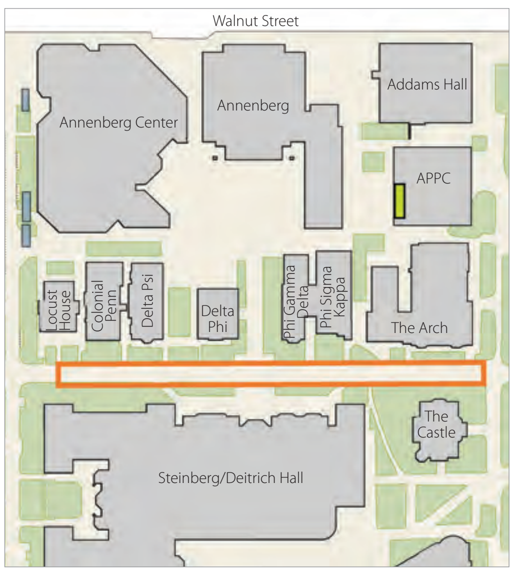
- *Existing tree credit 3600 block: 12,749 sf*
- *Existing tree credit 3800 block: 6,487 sf*
- *Existing tree credit 3900 block: 9,787 sf*
- *Total Impervious area disconnected: 29,023 sf*

PROJECT BOUNDARY

EXISTING GREEN SPACE

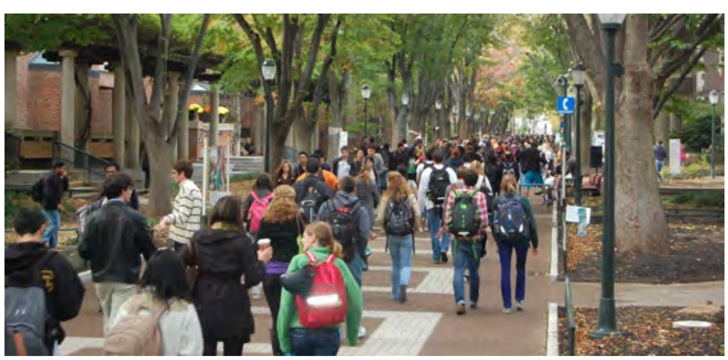
EXISTING TREE CREDITS

Location map - 3900 and 3800 Blocks of Locust Walk



Location map - 3600 Block of Locust Walk

3900 Block of Locust Walk view East



3600 Block of Locust Walk view West

Shoemaker Green

200 S. 32nd Street

Approved - July 27, 201

Shoemaker Green view North

Project Description

The Shoemaker Green project is located south of the intersection of 33rd and Walnut Streets and involves 2.9 acres of earth disturbance. This area is located west of the Palestra and Hutchinson Gym, and north of Franklin Field. Prior to this project, this area included surface tennis courts and asphalt paving. The project transformed this area to an open public space with lawn and pedestrian walkways. Stormwater management is provided by two bioretention systems and a subsurface detention system. The project also includes a cistern to be used for irrigation.

Stormwater Management Description

The project decreased impervious coverage by more than 20% from pre-development conditions; therefore it was only subject to PWD's Water Quality component of the Philadelphia Stormwater Regulations and was exempt from Channel Protection and Flood Control requirements. Included in this decreased impervious area consideration were existing and new tree credits. Areas that are considered disconnected do not require water quality management per PWD requirements. Management of DCIA is accomplished by a series of stormwater management practices, including two (2) bioretention systems and one (1) subsurface detention system.

The subsurface detention system is approximately 22,300 square feet in area and is installed over top of a portion of the previous impervious tennis courts. A portion of the tennis court was left in place in this area in order to provide an impervious bottom to the detention system. The detention bed receives

Location map - Shoemaker Green

ground surface runoff via inlets and trench drains, which connect to a perforated distribution pipe within the middle of a 12-inch thick stone layer, wrapped in non-woven geotextile fabric, located on top of the tennis court. A 3-foot depth of planting soil is located above the stone. The system utilizes a Smartdrain underdrain system that collects and slowly releases the stored water within the system. The perforated distribution pipe is connected to a junction box which contains an overflow pipe that allows larger storms to discharge from the system into the combined sewer located within the drive aisle to the north of Franklin Field.

There is a bioretention system utilized for stormwater management at the site. Bioretention Area BR-1 is approximately 1,642 square feet in area and is situated south of the southwest corner of the David Rittenhouse Laboratories building, and just east of 33rd Street. This system receives ground surface runoff via inlets and trench drains. Due to large fluctuations in tested infiltration rates, these systems were not designed for infiltration. The bottom of the bioretention systems are lined with an impervious liner. Smartdrains rest above the liner in a bed of sand to collect and slowly release stored water within the system. A 2.5 foot layer of planting soil rests above the Smartdrain system. A mixture of trees, shrubs, and grasses were planted within the bioretention systems. Overflow structures consist of domed grate inlets and are set so that the ponding depths of these systems is approximately 8-10 inches. Overflows ultimately discharge to the combined sewer located within the drive aisle to the north of Franklin Field.

The Smartdrain system utilized in both the subsurface detention system and the bioretention system provides subsurface drainage and slow release of the stormwater stored within these systems. The product is a device which is fitted with downward facing micro channels, which work by capillary action and convey water at a slow rate. The micro channels are then connected to a collection pipe at a downward angle creating a siphon action along the micro channels.

Shoemaker Green Rain Garden

Inlets contain water quality inserts manufactured by Suntree Technologies. These inserts consist of a basket with different size filter screens which capture sediment and debris and which must be periodically replaced.

The project also includes a 20,000 gallon concrete cistern for landscape irrigation. The cistern is an additional feature for the project, as it was not considered in the design for compliance with the Philadelphia Stormwater Regulations. The cistern is located to the east of Bioretention BR-1, below the pedestrian pathway.

A concrete box with piping to the subsurface detention system has been provided adjacent to the Hutchinson Gymnasium. The intent of this feature is to collect air conditioner condensate from the building in the future.

- *Tree Credit: 16,222 sf*
- *Subsurface detention management: 9,344 sf*
- *Bioretention BR-1: 13,161 sf*
- *Bioretention BR-2: 8,492 sf*
- *Total Impervious area managed or disconnected: 47,219 sf*
- *Total Impervious area within project limits that is not managed: 17,668 sf*
- *Volume of runoff managed: 3,935 cubic feet*

Shoemaker Green view North

POTENTIAL STORMWATER MANAGEMENT PRACTICES FOR FUTURE PROJECTS

Stormwater management technology continues to evolve as a result of increased regulatory requirements and a desire to create sustainable solutions that attempt to restore the natural hydrologic cycle by mimicking natural processes such as infiltration and bio-retention. Penn has already embraced some of these storm water management practices (SMP's) in the form of green roofs, bio-retention areas, and porous pavements, as described in Section 3.

Stormwater management before the 1970's focused mainly on collecting and conveying runoff off-site in as efficient a manner as possible. This out-of-sight-out-of-mind tactic often resulted in the transfer of drainage problems to unfortunate downstream property owners. In the 1970's, a minor shift in emphasis from drainage removal systems to safer conveyance of stormwater runoff peak discharges led to an understanding of risks, predicting financial impacts, and attempts to control property damages caused by stormwater. The 1990's brought the era of focussing on surface water quality the initial stages of the treatment component into stormwater management. At the beginning of the 21st century, concerns regarding the depletion of fresh water supplies brought an emphasis to engineer systems that considered runoff as a groundwater recharge resource rather than a wasted discharge.

This section identifies a number of innovative practices which Penn and its consultants may want to consider as storm water management strategies for future development and redevelopment projects.

These contemporary practices include utilizing modular green building components, storm water capture and reuse systems, green hardscape treatments, green streetscapes, bio-infiltration systems and evapotranspiration components.

While a number of the described practices include specific products that are commercially available, their mention in this document is not intended as endorsements of the products or their manufacturers. Rather, the vendor/product information is provided to facilitate further research into new technologies and their applicability to specific design projects.

Green Roofs

A green roof system is an extension of the existing roof which involves a high quality water proofing and root repellent system, a drainage system, filter cloth, a lightweight growing medium and plants. Green roof systems may be modular, with drainage layers, filter cloth, growing media and plants already prepared in movable, interlocking grids. Alternatively, each component of the system may be installed separately. Green roof development involves the creation of "contained" green space on top of a human-made structure. This green space could be below, at or above grade, but in all cases the plants are not planted in the ground.

Green roofs can provide a wide range of public and private benefits. Green roofs manage storm water by capturing rainfall in the growing medium of the roof system. Some of the rainfall is used by the roof's plants, some is evaporated from the soil, and excess water is gradually released from the growing medium to drain to the roof's downspout system.

Penn has installed full or partial green roofs on several buildings on campus, including the retail area of the Radian, the Hill Pavilion entry plaza at the School of Veterinary Medicine, Koo Plaza at Huntsman Hall, the Claire Fagin Hall courtyard at the School of Nursing, and English College House. These roofs consist of both extensive (thin growing medium) roofs and intensive (thick growing medium).

Some of the benefits realized from these installations include cost savings from the Philadelphia Water Department's (PWD's) storm water billing practice. According to PWD regulations, a green roof with a minimum growing medium thickness of three inches provides sufficient storm water management to be eligible for full storm water credit (that is, no storm water fee is charged for the building's roof area). Full credit can also be obtained for up to one third of a building's roof area not constructed as a green roof if it is directed to the remaining two-thirds (or more) of a building's roof area constructed as a green roof. This allows for the placement of air handling equipment and/or elevator towers on a building's roof without losing the opportunity for full storm water credit.

Additionally, the use of a green roof can contribute towards the 20 percent reduction in existing impervious area for a redevelopment site, so that the project is exempted from the Flood Control requirements and avoids the construction costs of large detention systems.

In addition to reductions in stormwater construction costs and PWD stormwater fees, green roofs can provide other benefits. A building can be designed with rooftop access and the green roof can become a public gathering place. The green roof growing media acts as additional insulation and can help reduce heating and cooling costs for the building. While green roofs have higher initial construction costs than conventional roofs, the green roof layer also protects the roof membrane from the natural elements, especially the ultraviolet radiation of the sun that contributes to the breakdown of synthetic roof materials, so that the life cycle of a green roof can significantly exceed that of a conventional roof.

Another trend in stormwater management for building roofs is the construction of "blue" roofs. These are essentially green roofs without the green, that is, the roof is designed as a detention system for rainwater to pond on the roof, which is then slowly released via restrictions on the roof drains. A blue roof is viewed as a detention system by PWD. It does not qualify towards the 20 percent reduction in existing impervious area, but it will reduce the stormwater fee associated with the building if the roof is designed to manage the first inch of runoff via slow release.

Products

Until recently, most green roofs have been designed by green roof "experts" in conjunction with a project's architect. However, numerous pre-fabricated green roof systems are being developed that simplify the design and installation of the roofs, with some of them being especially well-suited to retrofit applications on existing buildings. Extensive systems are of the lightweight variety and typically support 3-inches of growing media, while intensive assemblies are more durable to foot traffic and incorporate media depths of 6-inches and greater. Several representative systems which are commercially available are described here.

Green Roof

1. GARDEN ROOF® ASSEMBLY

www.hydrotechusa.com 1-800-877-6125

- *Extensive and Intensive assemblies available*

Extensive Assemblies

- *Ideal for inaccessible roofs*
- *Can be used on flat or sloping roofs*
- *Reduce storm water runoff*
- *Help to mitigate the urban heat island effects*
- *Require minimum maintenance*

Intensive Assemblies

- *Require greater growing media depths 6"-36"*
- *Can be used for recreation*
- *Accommodate a wider variety of plants/shrubs/trees*
- *Must be irrigated*
- *Require regular maintenance*

Eco-Roof

2. ECO-ROOFS LLC

www.eco-roofs.com 1-269-471-7408

- *Recycled high density polyethylene (hdpe) plastic units*
- *3.3" standard depth — 2", 4", 6" and deeper options available*
- *Drainage channels in both directions molded in bottom of tray*
- *Minimal water reservoirs to avoid root rot*
- *Engineered growing media meets German FLL guidelines*
- *Plants can be grown to full establishment (95%+ coverage) with enough lead time*

Greengrid

3. GREENGRID® ROOF SYSTEMS

www.greengridroofs.com 1-847-918-4000

- *Module material 100 % pre-consumer recycled high molecular weight polyethylene protected with UV inhibitor and stabilizers.*
- *Drainage clearance above roof 1/2 in.*
- *Growth media proprietary engineered growth media blend of organic and inorganic components.*
- *Based upon German FLL standards.*
- *Vegetation Perennials, grasses, or shrubs specifically selected for climate, hardiness zone, color, and size.*

Liveroof

4. LIVEROOF™ SYSTEM

www.liveroof.com 1-800-875-1392

- *Natural Function Natural Beauty of built-in-place system*
- *Speed of installation of modules*
- *Plant diversity of 2 1/2"-6"of soil.*

Tectagreen

5. TECTAGREEN™ MODULAR SYSTEMS

www.tectaamerica.com   1-866-832-8259

- *A modular system can be assembled on-site*
- *Can be applied over the top of an already existing rooftop*
- *Complete with water retention fabric, 3.5" engineered growing media, and a succulent mix of plants*
- *Designed to retain large amounts of water*

Aqualok

6. AQUALOK™ SYSTEM

www.freedomgardenproducts.com   1-830-305-2299

- *Lightweight – Well suited for existing structures and avoids costly structural modifications*
- *Full-Time storm water detention system – water does not drain out through soils other systems employ*
- *All the landscape options typically only available with 12" deep heavy soil systems*
- *Thin profile avoids interference with mechanical equipment, perimeter roof flashing, and accessible terraces.*
- *Significantly less components make for a quick, low-tech installation*
- *No soil to haul, place*
- *Ease of access to roof membrane to locate leaks*

Muellner

7. MUELLNER GREEN ROOF SYSTEM

www.resisolutions.com   1-763-784-0614

- *Deep System allows for growth of a greater variety of turf and plants*
- *Supports normal lawn and recreational uses*
- *Provides both storm water control and plant irrigation*
- *Provides greater insulating properties*

Applications

1. NEW CONSTRUCTION

Advantages

- *Ease of installation*
- *Warrantied products*
- *Interchangeable modules*
- *Numerous planting theme varieties*
- *Provide Heating/Cooling Benefits*
- *Provide Storm water Runoff Reductions*

Disadvantages

- *Additional capital investment*
- *Perishable construction item*
- *Not applicable to irregular shapes*
- *Installation may be in out of sight area*
- *Emergency snow removal labor intensive*

2. RETRO-FITTING EXISTING STRUCTURES

Advantages

- *Ease of installation*
- *Both flat and sloped roof applications*
- *Warrantied products*
- *Interchangeable modules*
- *Numerous planting theme varieties*
- *Provide Heating/Cooling Benefits*
- *Provide Storm water Runoff Reductions*

Disadvantages

- *Additional capital investment*
- *Perishable construction item*
- *Not applicable to irregular shapes*
- *Installation may be in out of sight area*
- *Emergency snow removal labor intensive*
- *Existing roof support structural analysis required*

Green Walls

Green wall concepts have been in existence for centuries with examples in architecture dating back to the ancient Babylonians, exemplified by one of the seven ancient wonders of the world, the Hanging Gardens of Babylon. Many cultures trained grape vines to climb vertically, while manors and castles displayed climbing roses on many building facades. Since the 1920s, features such as pergolas and a variety of self-clinging climbing plants have been developed.

Typical green walls provide little opportunity for stormwater management and may in fact require irrigation to sustain the vegetation. However, an intriguing application would be to use captured roof stormwater runoff to irrigate the plants.

Self-clinging plants such as English Ivy have commonly been used to create green walls. Their sucker root structure enables them to attach directly to a wall, covering entire surfaces. These aggressive plants can damage unsuitable walls and make building maintenance and plant removal more difficult.

To reduce negative impacts to buildings, stainless steel cable and wire rope net structures have been introduced into the marketplace over the last several decades and their use has become commonplace. These systems allow for the plant material to thrive and expand vertically while remaining detached from the building structure, thus reducing damage and maintenance concerns.

PWD's Stormwater Management Guidance Manual does not include green walls. However, stormwater credit might be obtained by using captured rain water to irrigate a green wall inside a building.

Greenscreen

Eco-Mesh

Products

1. GREENSCREEN

www.greenscreen.com 1-800-450-3494

- *Wall Mounted components*
- *Column applications*
- *Free Standing Screens*
- *Shade and Light Contral*
- *Graffiti Control*
- *Security partitions*

2. ECO-MESH® MODULAR PLANT TRELLIS

www.mcnichols.com 1-877-884-4653

- *Enhances the appearance of structures and areas*
- *Hides unsightly equipment and unattractive building features*
- *Creates privacy screens using natural elements*
- *Cleans and cools air*
- *Helps to buffer wind and sound.*
- *Decreases energy consumption by regulating air temperature*

Applications

1. NEW CONSTRUCTION

Advantages

- *Ease of installation*
- *Provides positive aura – supplements green building components*
- *Warrantied products*
- *Numerous planting theme varieties*
- *Provide Heating/Cooling Benefits*
- *Air Quality benefits*

Disadvantages

- *Additional capital investment*
- *Perishable construction item*

2. RETRO-FITTING EXISTING STRUCTURES

Advantages

- *Ease of installation*
- *Can provide a "green" perception at lower cost to other green building components*
- *Warrantied products*
- *Numerous planting theme varieties*
- *Provide Heating/Cooling Benefits*
- *Air Quality benefits*

Disadvantages

- *Additional capital investment*
- *Perishable construction item*

Capture and Reuse

Capture and storage of rainwater for reuse at later times has been practiced for centuries. It is only in the last few decades that this practice has been adopted in U.S. urban settings. Due to the low cost of public water and the added cost of constructing a water treatment system and a secondary plumbing system, the economics of this practice can be difficult to justify, especially as a retrofit practice to an existing building or site. However, with new construction, the right combination of rainfall catchment area and water demand may make the practice economically desirable and operationally feasible.

Capture/reuse systems can range from small rain barrels for garden watering to large surface cisterns or subsurface tanks storing thousands of gallons of captured rainwater. The rainwater may be reused for external uses such as landscaping or vehicle washing, or for internal building uses such as toilet flushing, industrial process water, or fire protection.

For external non-potable uses, the rainwater may be able to be reused without any water quality treatment prior to use. The Philadelphia Water Department (PWD) requires that storm water management systems be completely drained within 72 hours of a rainfall event so that the system capacity is fully available for a subsequent rainfall event. It should be noted that PWD does not give storm water management credit for capture/reuse systems used for landscape irrigation. Since irrigation will not occur during the winter months, there is no mechanism for draining the system within 72 hours. Also, within three days of a rain event, it may not be necessary to irrigate the landscape, so the system will not be drained. However, automated systems have been developed that link real-time weather forecasting with pump systems that will draw down the stored rainwater in anticipation of an impending rainfall event. The pump system could be designed to meet the slow release requirements of PWD's storm water regulations, thereby making the system potentially eligible for stormwater credit.

For internal uses, some level of water quality treatment is typically required depending on the proposed use of the captured rainwater. In addition to the added costs of a cistern and a water treatment system, these internal systems typically require a parallel plumbing system so that water can be provided from the public water system during periods when the cistern is empty. For the University, these systems would be most practical in buildings that are occupied year-round, so that a constant demand is available to draw down the captured rainwater volume. Administration buildings and research facilities may be better suited for this technology than residential buildings or dining halls.

These systems are typically designed by a project's mechanical/electrical/plumbing (MEP) engineer in coordination with the project architect who helps establish anticipated water demands from the building's occupants. A number of simple models are publicly available to aid in the sizing of cisterns based on local rainfall patterns; one such model is available online from North Carolina State University. www.bae.ncsu.edu/topic/waterharvesting/model.html

Products

Numerous small rainbarrel products are available for the private homeowner. However, systems suitable for use on large university buildings are typically designed by engineers using commercially available storage tanks, pumps, and control devices.

Applications

1. NEW CONSTRUCTION

Advantages

- *Can reduce utility usage costs*
- *Potential storm water reduction credits*
- *Educational opportunities*

Disadvantages

- *Additional capital investment*
- *Additional infrastructure may be required for utilization*

2. RETRO-FITTING EXISTING STRUCTURES

Advantages

- *Can reduce utility usage costs*
- *Potential storm water reduction credits*
- *Educational opportunities*

Disadvantages

- *Additional capital investment*
- *Additional infrastructure may be required for utilization*

Green Hardscape Treatments (Porous Pavements)

Porous pavements have been in existence for almost 40 years. The first systems were installed in the mid-1970's and have been extensively monitored and evaluated. The major misconceptions regarding porous pavement are that it easily clogs and offers no significant durability in either water permeability or load carrying capacity. The extensive research conducted to date shows that in general, water infiltration durability is a function of maintenance. The best performing systems in relation to water permeability are those that were protected during the construction period of the project and biennially swept by vacuum, while the most structurally durable systems are those installed in light duty traffic areas such as parking lots, alleys, minor access drives and pedestrian areas.

Penn has constructed porous pavements on several projects on the campus; for example, porous asphalt at Weiss Pavilion and a permeable paver system constructed for Woodland Walk, both of which incorporate open joints between the paver units that allow for stormwater runoff to drain through the walkway into a subsurface infiltration system below the pavement. Porous asphalt and porous concretes can be ordered and delivered to most project sites from pre-mix plants, identical to traditional asphalt and concrete ready-mix applications. Additionally, pre-manufactured products are available and are becoming increasingly popular for paving and hardscape projects as discussed below:

Ecopave

Permapave

Netpave

Products

1. *ECOPAVE*

www.irvmat.com   1-317-536-6650

- *Porous concrete mixture*
- *Reduces potential detention area size*
- *25% void space provides water infiltration pathway*
- *Leed credits for use*
- *Storm water filtering effect*

2. *PERMAPAVE*

www.permapave.com   1-473-762-7283

- *Modular paving blocks*
- *Natural stone components*
- *Reduces potential detention area size*
- *1.5 gal/sf infiltration rate*
- *Storm water filtering effect*

3. *NETPAVE®50*

www.resisolutions.com   1-4713-784-0614

- *Parking on grass or gravel surfaces*
- *Made from 100% Recycled plastic*
- *Modular and light weight for quick and easy installation*
- *Flexible shape can be cut to fit uneven and irregular surfaces*
- *Strong enough to support heavy vehicles*
- *Permeable, allows water to flow through the surface*
- *Grass can still be mowed*
- *Surface can be snowplowed when edges are secured*

Applications

1. *NEW CONSTRUCTION*

Advantages

- *Increased groundwater recharge*
- *Positive public relations*
- *Custom applications can be accommodated*
- *Low initial maintenance*
- *LEED applications*

Disadvantages

- *Higher installation costs*
- *Long term maintenance concerns*
- *Perception of system frailty*

2. *RETROFIT*

Advantages

- *Increased groundwater recharge*

- *Positive public relations*
- *Custom applications can be accommodated (irregular shapes, difficult access)*
- *Low initial maintenance*
- *LEED applications*

Disadvantages

- *Demolition concerns*
- *Higher installation costs*
- *Long term maintenance concerns*
- *Perception of system frailty*
- *Why fix it if it wasn't broke syndrome*

Green Streets

Green Streets is a concept that has evolved primarily due to the need to retrofit existing urbanized areas in order to reduce impervious ground cover in hopes of reducing combined sewer overflows (CSOs). Increased regulatory emphasis on CSOs has pressured utility operators to attain programmatic goals of controlling the source of storm water, limiting its transport and pollutant conveyance to the collection system, restoring predevelopment hydrology of drainage areas to the extent possible, and providing environmentally enhanced roads. Realized benefits of these achieved goals have helped to expand the green street concept beyond CSO problem areas and into many other urbanized locations. Many communities across Europe, South America, and North America have taken the concept even further by promoting community events centered on green street areas, temporarily closing down streets to vehicular traffic and creating recreational park and festival-like atmospheres. Green Streets implementation strategies encompass several best management practices, including bio-retention, porous pavements, green canopies, and the use of vegetated drainage conveyance paths.

The Philadelphia Water Department (PWD) has begun a green streets initiative to foster design guidelines and construction of demonstration projects on smaller alleyways and low-traffic streets. Green streets principles could be applied to private driveways within the University campus. Opportunities may exist for the University and PWD to collaborate on converting an existing city street running through the campus into a green street. Such a project might include directing clean stormwater runoff from University building roofs to stormwater management systems located within the city street's right-of-way and cost-sharing between the university and the city for construction and maintenance.

Bioretention Products

Bio-retention is accomplished through the strategic location of small scale engineered eco-systems designed to retain certain amounts of storm water through the natural absorption and transpiration qualities of plants and soil structures. Many natural processes occur within bio-retention cells: infiltration and storage reduces runoff volumes and attenuates peak flows; water-purifying biological and chemical reactions occur in the mulch, soil matrix, and root zone; and storm water is filtered through vegetation and soil. Excess runoff is typically managed via an overflow outlet that drains to an underground detention system or directly to the public sewer system.

Penn has constructed a bioretention area at the Music Building and several bioretention areas have been constructed at Penn Park. These systems manage storm water by capturing runoff in a landscaped surface depression.

While many gardens are constructed from individual components, several manufacturers have developed prefabricated rain garden systems, primarily for installation in paved environments.

Freno

1. FRENO™ MODULAR RAIN GARDENS

www.frenosystems.com   1-800-789-08720

- *Modular precast concrete system installs rapidly*
- *More economical installations compared to built-in-place systems*
- *Suitable for storm water planters, curb extensions, bio-retention areas, vegetated swales, green gutters or rain gardens.*
- *Works equally well for filtration or infiltration based systems.*
- *Multiple attractive color and finish options.*
- *Vertical walls maximize storm water storage capacity.*
- *Available with recycled content.*
- *Unlimited Design Options*

MWS

2. MWS-LINEAR MODULAR WETLANDS

www.modularwetlands.com   1-760-433-76403

- *Catch Basin Structure*
- *Settling Chamber*
- *Perimeter Filter*
- *High Flow Internal By-Pass*
- *Multi-Level flow control valves*

Structural Soil Cell Products

Structural Soil Cells have been developed to eliminate root development conflicts between environmentally favorable street trees and adjacent paved surfaces, curbs and underground utilities. Several manufacturers have developed prefabricated cellular structures that promote deep root development while minimizing conflicts with adjacent infrastructure.

Silva Cells

1. SILVA CELLS®

www.deeproot.com   1-800-458-7668

- *Filled cells of loose high quality soils*
- *Promotes deep root systems for trees*
- *Cell structure eliminates potential pavement damage due to shallow root penetration*
- *Manages storm water rates, volumes and quality*
- *Accommodates traffic loading*
- *Restores soil eco-systems in retrofit applications*

Strata Cell

2. STRATA CELL®

www.citygreen.com 1-800-458-7668

- *Modules assemble to form an interconnected matrix, so applied loads are shared evenly and lateral strength maximized.*
- *In excess of 94% of total soil volume is available for tree-root growth.*
- *Generously designed apertures permit common conduits, service pipes and aeration systems.*
- *Long-term root-zone management*
- *Made from 100% recycled polymers*
- *Super-efficient assembly time on site*
- *Ultra-Strong and Low Strength modules are available*
- *No steel components required for strength*

Applications

1. NEW CONSTRUCTION

Advantages

- *Increased groundwater recharge*
- *Positive public relations*
- *Attractive*
- *ıncreased water quality*
- *Reductions in heat island effects*
- *Low maintenance systems*
- *Potential LEED applications*

Disadvantages

- *Increased capital investment*
- *Maintenance concerns – re-training of crews*
- *Perception of system frailty*

2. RETROFIT

Advantages

- *Increased groundwater recharge*
- *Positive public relations*
- *Attractive*
- *Increased water quality*
- *Reductions in heat island effects*
- *Low maintenance systems*
- *Potential LEED applications*

Disadvantages

- *Demolition concerns*
- *Increased capital investment*
- *Maintenance concerns – re-training of crews*
- *Perception of system frailty*
- *Why fix it if it wasn't broke syndrome*

Meadow as a Stormwater Management Practice

The conversion of turf areas to meadow is defined as "Landscape Restoration" in the Pennsylvania Stormwater Best Management Practices Manual. While PWD's regulations and fee structure do not provide any specific incentives for the use of meadow grasses, their use can provide a number of environmental benefits that can also result in cost savings:

- *Reduced runoff volumes and rates from meadow grasses vs. turf grass can result in smaller stormwater management structures.*
- *Deeper root growth of meadow grasses promotes increased infiltration, and greater plant mass results in increased evapotranspiration.*
- *Native meadow grasses require less irrigation, fertilizer, herbicides, and pesticides than turf grass.*
- *Reduced mowing of meadow grasses results in lower labor costs, equipment costs, gasoline usage, and noise pollution when compared to turf grass maintenance.*
- *Native vegetation provides improved habitat for native insects. A healthy insect population attracts birds, which control insect pests as well.*

To maximize success of the meadow conversion, existing soils should be amended based on the recommendation of a horticulturalist or landscape architect. The Pennsylvania Stormwater Best Management Practices Manual provides guidance on the establishment and maintenance of meadow areas.

Meadow in Penn Park

FINDING SUSTAINABLE STORMWATER MANAGEMENT OPPORTUNITIES

This section provides the block-by-block analysis of the campus, identifying potential opportunities for stormwater retrofitting, shared stormwater management facilities, and possible options for future construction of facilities described in the *Penn Connects* and *Penn Connects 2.0* studies. The intent of this distributed approach is to manage rainfall where it falls, rather than concentrating and conveying it via pipes to other locations. For new construction projects, the PWD regulations require that the first inch of runoff from impervious surfaces be infiltrated. However, whether this requirement can be met is determined by the soils existing at the proposed site.

Infiltration and Campus Soils

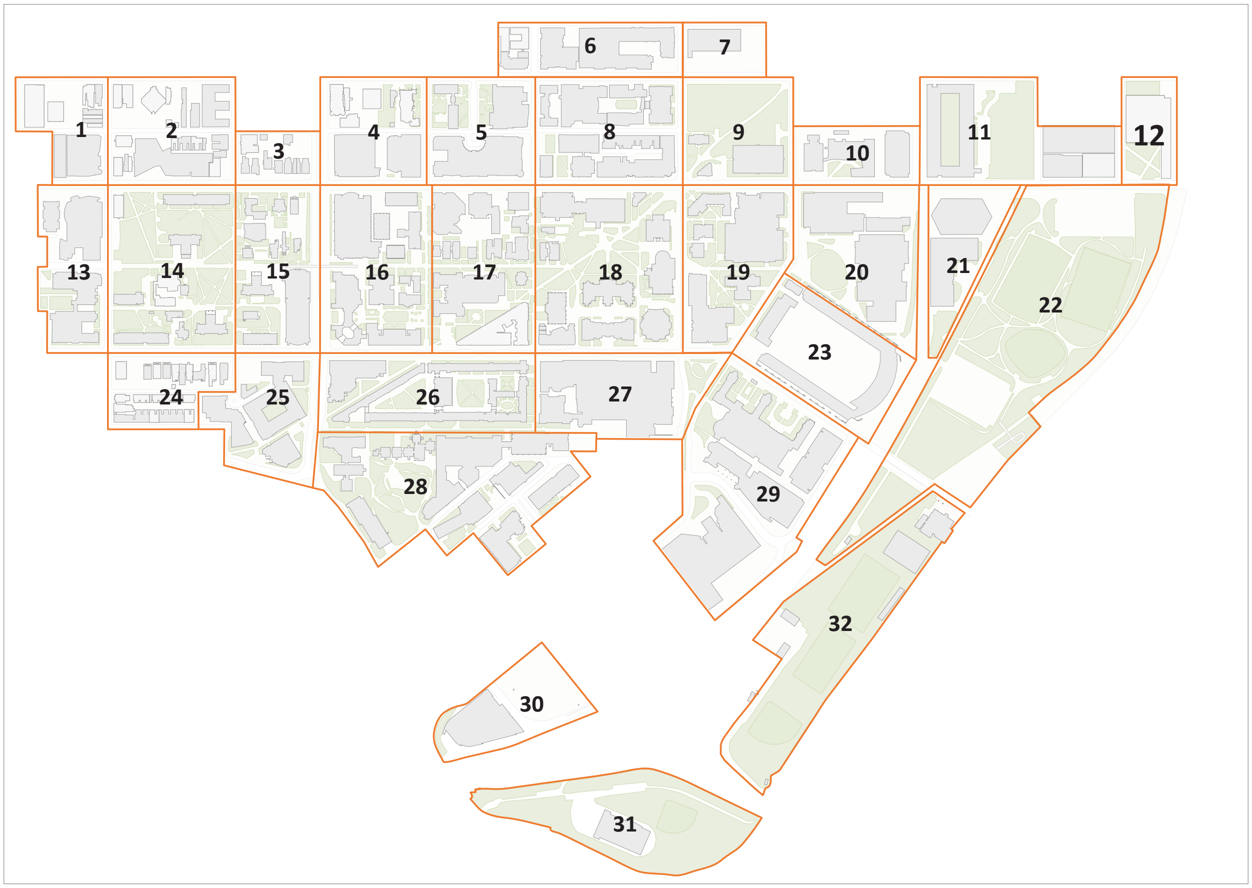
According to the U.S. Department of Agriculture's Natural Resources Conservation Service Soil Survey, 100 percent of the campus study area consists of Urban Land (Ub) soils. The characteristics of these soils are highly variable and may consist of severely disturbed original soils or imported urban fill of varying composition. Infiltration rates for urban soils can vary widely, from very low due to compaction or fine clay/ash content to very high due to past use of rubble as fill or the presence of large subsurface voids resulting from prior building demolitions.

Due to this high degree of variability, PWD requires that infiltration testing be conducted on all proposed construction sites (that exceed 15,000 square feet in disturbance and must therefore comply with the stormwater regulations). Ideally, this testing is performed using a double-ring infiltrometer, in a test intended to represent the infiltration process occurring at the base of an infiltration system. The testing must be completed within the area of the proposed infiltration facility, and at a depth matching the proposed bottom of the system.

To meet PWD's requirements, infiltration test rates must fall within the range of 0.5 to 10 inches per hour. Rates below 0.5 inches per hour may not allow a system to drain within the required 72 hours, and may indicate an already dense soil that will be more prone to clogging of the underlying soil pores, resulting in a premature failure of the infiltration system. Rates above 10 inches per hour may indicate excessive voids in the underlying soil structure which may become unstable with the introduction of infiltrated stormwater. PWD will allow infiltration on sites with test rates above 10 inches per hour but will require soil amendments or compaction methods to lower the infiltration rate.

To reduce the potential for problems with the structural integrity of building foundations and the inflow of infiltrated stormwater into building basements, PWD requires that infiltration systems be located at least 10 feet downgradient and 100 feet upgradient of existing or proposed structures. To reduce the potential for problems on adjoining properties, infiltration systems must be located at least 10 feet from property lines.

If the infiltration capacity of a construction site's soils does not meet PWD's requirements, then the first inch of runoff from impervious surfaces must be captured in surface or subsurface detention



Block-by-block division of the University of Pennsylvania study area

systems and discharged via slow release at a rate not exceeding 0.24 cubic feet per second per acre of impervious area. For combined sewer areas, such as the majority of Penn's campus, twenty percent of the one-inch runoff volume must be routed through volume reducing practices such as a green roof or a bioretention area.

Of the projects constructed on campus since 2006 (and summarized in Section 3), five project sites include PWD-approved infiltration systems (Weiss Pavilion, Music Building, Class of '62 Walkway, Woodland Walk, and Golkin Hall). PWD does not require infiltration testing for porous pavement systems, however it is recommended that the existing subsoils located beneath a proposed porous pavement system be evaluated with a visual inspection at a minimum, and preferably with infiltration testing. If runoff that passes through the pavement is unable to infiltrate, problems with pavement heaving in winter or pavement subsidence due to soft soils or large voids could occur.

Trading and Banking of Impervious Areas and Stormwater Management

Before outlining the procedural framework for stormwater management, the concepts of "trading" and "banking" should be defined. PWD supports this approach on large multi-building parcels such as college campuses or business parks. As an example of "trading", suppose the University proposes construction of a new building but is not able to provide stormwater management for the structure due to space limitations or because a green roof is not feasible for the proposed building. To meet the required stormwater management, the University could retrofit an existing impervious area on the same block or within several blocks from the project. An existing building might be retrofitted with a green roof of the same area as the proposed unmanaged building, or an existing parking lot might be converted to porous pavement such that the new pavement area matches the area of the proposed building. Under this scenario, the University has not advanced its overall net campus runoff as a result of the proposed construction.

As an example of "banking", suppose the University has two projects planned within the same block or within a few blocks of each other: one project is a new building and the second project is the reconstruction of a large existing parking area as part of a scheduled repaving operation. To provide the stormwater management for the new building, the University proposes to "trade" impervious area by reconstructing a portion of the existing parking area as porous pavement, with an area of porous pavement equal to the new building's impervious area. However, the University can take the project to the next "banking" level by repaving additional areas of the existing lot with porous pavement. This pavement area now exceeds the PWD stormwater management requirements and can be "banked" for future construction projects, e.g. other new buildings or parking areas in the vicinity of the project.

These trading/banking projects need to be fully vetted with PWD. Typically, PWD wants the various sites of a trading/banking project to be located within the same sewershed so that the projects result in no net increase to any specific sewer. Also, PWD may place restrictions on how long the additional stormwater management may be banked.

A Procedural Framework for Stormwater Planning on a Block-by-Block Basis

The information provided in the block-by-block diagrams in this section can be used in a phased approach to stormwater planning for new or retrofit construction projects. This approach considers existing site and utility constraints and opportunities for shared stormwater management facilities. In addition to frameworks for new and retrofit projects, a separate approach is provided for potential green street projects.

New Construction

1. *Identify project requirements - Prepare the conceptual layout of the site including the building footprint, parking requirements, and pedestrian walkways. Identify potential locations for ground-level stormwater management facilities adjacent to the proposed building or structure.*
2. *Review planned construction on adjoining blocks - Using the block-by-block diagrams, identify new projects and potential retrofit projects across the streets from the proposed new construction. These adjoining projects may include repaving of existing parking areas, reconstruction of existing sidewalks, or repair/replacement of roofs on existing buildings.*

3. *Identify existing utilities in the streets surrounding the proposed new construction - determine if existing utilities propose obstacles to cross-street transfer of stormwater runoff via underground pipes.*
4. *Consider "banking/trading" options - In the event that existing utilities prevent the conveyance of stormwater across adjoining streets, the University might also consider "banking" or "trading" impervious area as described above. Using the block-by-block diagrams, identify multiple projects in one area that might "trade" impervious areas to meet PWD requirements, or consider construction of surplus stormwater management capacity to be applied towards a future project.*
5. *Identify existing utilities within the block of the proposed construction - Locate all existing utilities in the vicinity of the proposed construction to ensure there are no conflicts with the proposed building or potential stormwater management locations.*
6. *Identify shared facility options - Shared facilities are limited to surface or subsurface systems, such as surface bioretention areas located in open green areas or subsurface infiltration/ detention systems located beneath parking areas. If such a system is to be constructed as part of a new construction project, consider overdesign of the system volume to allow for management of runoff from adjacent existing buildings or paved areas. Using the block-by-block diagrams as a guide, determine the feasibility of connecting roof drains or storm inlets from these existing facilities to the new shared facility.*
7. *Identify green roof potential for new and existing buildings - Constructing the new building with a green roof will reduce the size of ground-level stormwater management facilities. It may also help the project achieve the 20 percent reduction in existing impervious area that exempts a project from the costly Flood Control requirement. Depending on the green roof system employed, there may be reduced unit costs if adjacent existing buildings are retrofitted with green roofs at the same time. Use the block-by-block diagrams to identify potential green roof retrofits in the vicinity of the proposed project.*
8. *Conduct infiltration testing - At this point, a project has moved from the stormwater planning stages to the preliminary engineering stage. A determination of the feasibility for infiltration on the project site will further refine the list of stormwater management options, e.g. whether or not porous pavement will work.*
9. *Prepare conceptual stormwater design - With an understanding of the infiltration potential for a given site, the conceptual stormwater approach can be preliminarily designed. With this information, cost estimates can be generated that evaluate construction costs vs. reductions in PWD stormwater fees. Decisions can be made regarding the extent to which additional retrofitting or shared facilities are constructed. Section 6 of the master plan discusses stormwater construction costs and the PWD fees in greater detail.*

Retrofit Projects

Planning for retrofit construction projects follows a similar step-by-step approach as new construction. However, if a retrofit project is being considered only as a stand-alone project, the retrofitting should be considered as a part of the scheduled maintenance of the existing facility.

When an existing building roof requires repair or is scheduled for replacement, a green roof retrofit should be considered. The green roof retrofit construction cost may exceed that of conventional repair or replacement, but the increased cost will be offset by the reduction of the monthly PWD stormwater fee (over the life of the building).

If an existing parking area or pedestrian walkway/plaza is scheduled for repaving or reconstruction, consider the use of porous pavement. Again, the retrofit cost may exceed the cost of conventional replacement, but the increased cost will be offset by the reduction of the PWD fee. The construction cost vs. PWD fee offset is discussed in greater detail in Section 6.

Green Streets – Opportunities for Public/Private Shared Facilities

City streets and sidewalks account for approximately 38 percent of the impervious area located within the City's combined sewer service area. Recognizing the significant runoff volume that these surfaces contribute to the combined sewer overflow problem, PWD has instituted a green streets initiative aimed at reducing street runoff. While PWD's primary interest in green streets is from a stormwater management perspective, a more holistic concept is that of "complete streets." This term refers to creating a streetscape environment that places the needs of the pedestrian ahead of the needs of the motor vehicle occupant.

The "complete street" encourages pedestrian and bicycle use, improves the quality of life by providing a safe and aesthetically pleasing environment, and provides stormwater management and increased green space which improves air quality and reduces the urban heat island effect. Typically, existing parking spaces near intersections are converted into vegetated stormwater management areas that protrude into the former parking lane. These "bump outs" or "curb extensions" have the effect of calming (i.e., slowing) traffic at intersections, exactly where most pedestrian-bicycle-motor vehicle conflicts may occur. The result is a safer, greener experience for the pedestrian and bicyclist.

Often, the primary obstacle to creating a green street is the number and complexity of existing utilities located within the street right-of-way. The utilities may interfere with the preferred placement of bioretention areas, tree trenches located in the sidewalk area that accept street and sidewalk runoff, or underground infiltration/detention facilities. As a result, open areas on private property adjacent to the street right-of-way may provide more opportunities for stormwater management system placement.

However, stormwater runoff from streets may be contaminated with gas, oil, antifreeze, battery acid, and heavy metals and other pollutants from internal combustion as well as tire and brake wear. The University may have liability concerns about introducing these contaminants onto their private property. In the worst case, a gasoline spill from a vehicle accident could quickly find its way into the street drainage system that leads to an infiltration/detention facility located on Penn's private property. Such contamination could lead to costly remediation, possibly including the complete removal of the stormwater system and remediation of the underlying contaminated soils.

Because input from PWD and the City Department of Streets would be required in the design of a green street on Penn's campus, analysis of green street potential on a street-by-street basis is beyond the scope of this master plan.

The Block-by-Block Analysis

The campus was divided into "32 blocks" in order to evaluate stormwater management opportunities on a smaller, more detailed scale. The City streets were typically used to define the extents of the blocks, however there may be locations where cross-block transfer of stormwater runoff is feasible. An AutoCAD drawing of the campus and aerial photography were used to evaluate the blocks for different types of stormwater management practices.

Using aerial photography and three-dimensional building representations from Google Earth, the Penn-owned buildings were evaluated for their potential for green roof retrofitting. Existing roofs were not considered viable for green roof retrofitting if the roof is pitched, if there is extensive mechanical equipment or towers on the roof, or if there are numerous roof areas at varying levels. Tray-type green roof systems may be feasible in the latter two conditions, but the focus of the evaluation was large, flat roof areas presenting few obstacles to green roof installation and maintenance. An analysis of the existing buildings' structural capacities to support retrofitted green roofs was not completed, nor were any on-site roof inspections undertaken. Both would be important next steps in the procedural planning framework outlined above.

Ground-level open areas were evaluated for their potential for porous pavement conversion, bioretention areas, and subsurface infiltration/detention systems. Detailed sizing of the systems was not performed. The maximum available open space is delineated in the block-by-block graphics and should be evaluated for existing utility conflicts as well as future development plans for the open areas. The feasibility of infiltration based on soil characteristics was not considered in the evaluation. In the event that the soils of an open area are infeasible for infiltration, underdrained bioretention areas or standard impervious asphalt/concrete pavements with subsurface stormwater management facilities could be employed.

Existing walkways and other paved areas were evaluated for their potential for pavement disconnection. If a paved area up to 75 feet wide drains via sheet flow to a vegetated area of equal or greater width and with less than a 5 percent slope, PWD considers this pavement disconnected. Stormwater management is not required for the disconnected pavement and the area can contribute towards the 20 percent reduction in existing impervious area which exempts a project from the costly Flood Control requirement. Disconnected pavement areas are exempt from the PWD stormwater fees.

Existing trees were evaluated for their disconnection credit. Existing trees located within twenty feet of paved areas are eligible for the disconnection credit. Fifty percent of the canopy area of the existing tree can contribute towards the 20 percent reduction in existing impervious area. The PWD stormwater fee can be reduced based on the canopy area that covers existing ground-level impervious area. New trees can also contribute to both the 20 percent reduction and PWD fee reductions, but potential new tree locations are not shown on the block-by-block diagrams.
All areas listed in the graphics should be considered approximate and will require further detailed analysis to determine feasibility.

Prior to the block-by-block diagrams, the following pages depict the various potential and existing stormwater BMP features on a campus-wide basis, to provide a general illustration of the distribution of the features across the campus.

Existing Green Roofs and Potential Conversions

Existing Porous Pavement and Potential Conversions

POTENTIAL POROUS PAVEMENT CONVERSIONS

EXISTING POROUS PAVEMENTS

Existing and Potential Bioretention Areas

POTENTIAL BIORETENTION AREAS

EXISTING BIORETENTION AREAS

Existing and Potential Subsurface Infiltration/Detention Systems

POTENTIAL SUBSURFACE INFILTRATION/DETENTION SYSTEMS

EXISTING SUBSURFACE INFILTRATION/DETENTION SYSTEMS

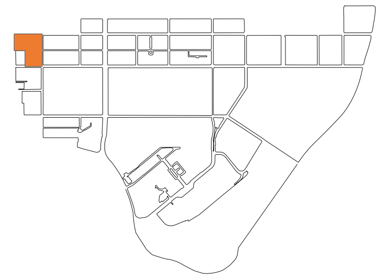
Existing and Potential Pavement Disconnections

EXISTING PAVEMENT
• Potential Disconnections

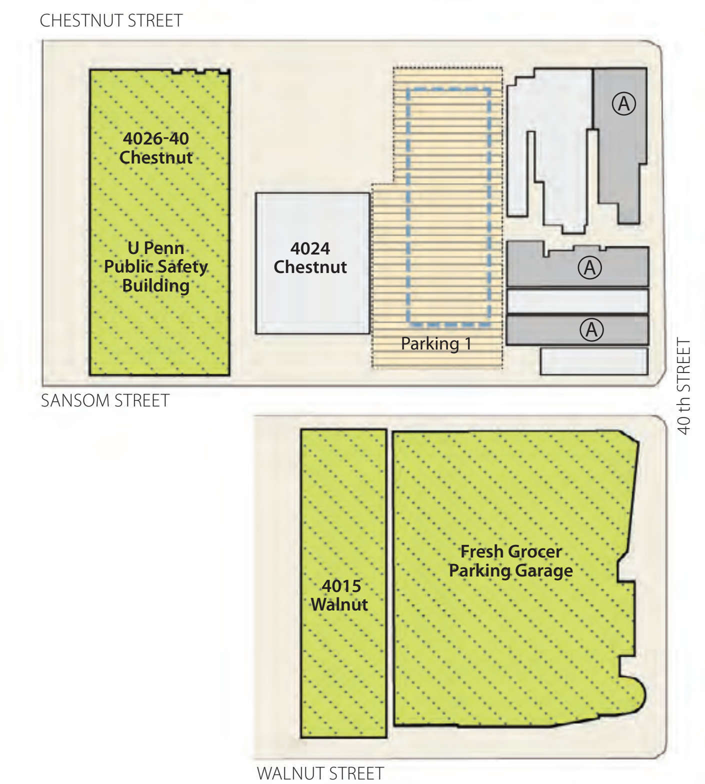
EXISTING PAVEMENT
• Existing Disconnections

Tree Credits

- EXISTING TREE WITH POTENTIAL TO BE CLAIMED AS TREE CREDIT
- EXISTING TREE CREDITS



Block 1



POTENTIAL GREEN ROOF CONVERSION
- 4026-40 Chestnut 22,290 sf
- 4015 Walnut 13,270 sf
- Fresh Grocer 36,480 sf

POROUS PAVEMENT CONVERSION
- Parking 1 16,240 sf

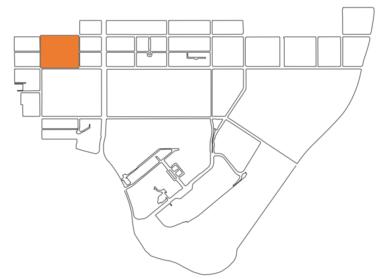
POTENTIAL SUBSURFACE INFILTRATION/DETENTION
- Shared Facility

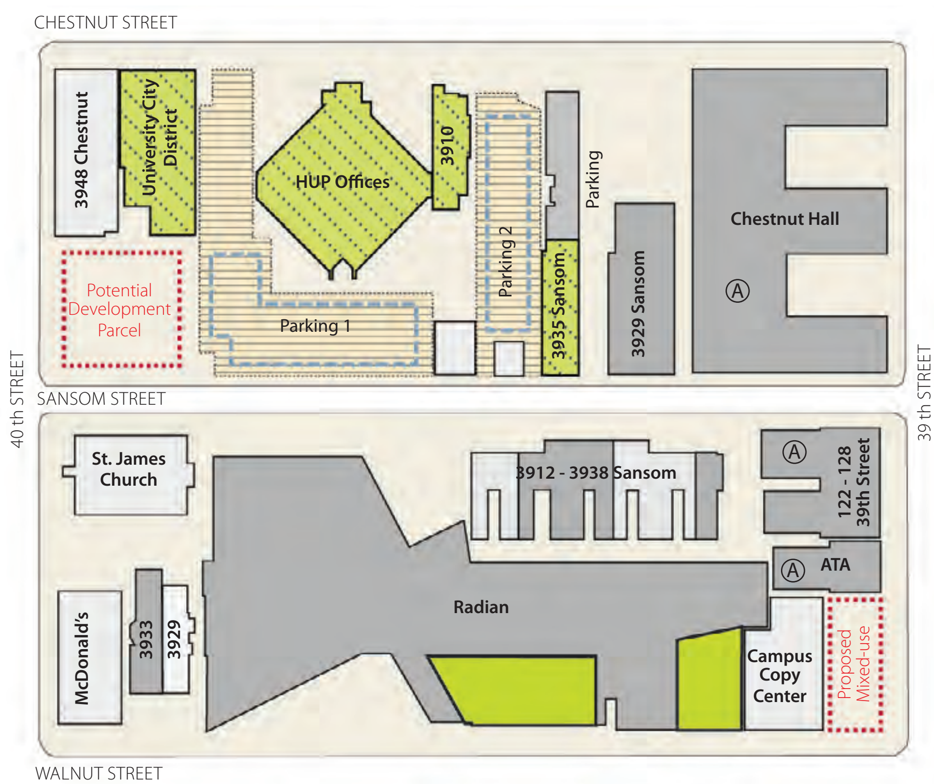
UNIVERSITY OWNED BUILDING
- No green roof proposed

NON - PENN OWNED BUILDING

Ⓐ • Buildings less feasible for green roof retrofit

Block 2





POTENTIAL GREEN ROOF CONVERSION
- 3948 Chestnut 5,420 sf
- University City District 5,900 sf
- HUP Offices 10,150 sf
- 3910 Chestnut 2,000 sf
- 3935 Sansom 2,290 sf
- 3929 Sansom 5,620 sf
- Chestnut Hall 26,200 sf

EXISTING GREEN ROOF
- Radian 11,010 sf

POROUS PAVEMENT CONVERSION
- Parking 1 15,970 sf
- Parking 2 9,700 sf

POTENTIAL SUBSURFACE INFILTRATION/DETENTION
- To manage pavement and rooftop run-off

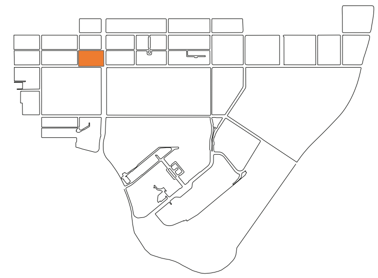
POTENTIAL SUBSURFACE INFILTRATION/DETENTION
- To manage pavement and rooftop run-off

PENN CONNECTS/POTENTIAL DEVELOPMENT
- Potential green roof

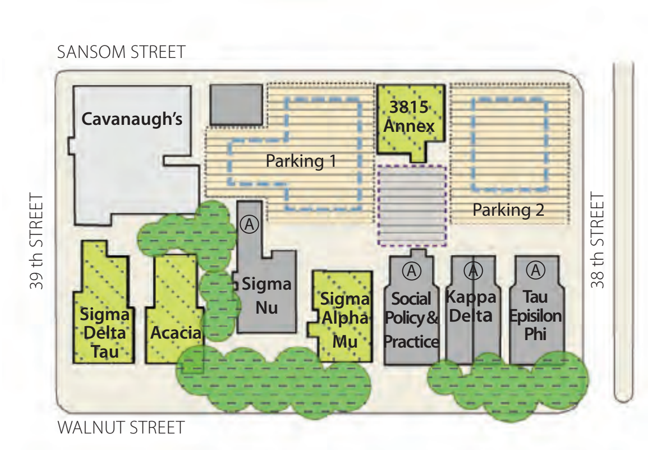
UNIVERSITY OWNED BUILDING
- No green roof proposed

NON - PENN OWNED BUILDING

Ⓐ • Buildings less feasible for green roof retrofit



Block 3



POTENTIAL GREEN ROOF CONVERSION
- Sigma Delta Tau 3,180 sf
- Acacia 2,850 sf
- Sigma Alpha Mu 3,100 sf
- Psych Annex 2,260 sf

POROUS PAVEMENT CONVERSION
- Parking 1 1,400 sf
- Parking 2 8,000 sf

POTENTIAL BIORETENTION AREA
(Remove existing concrete slab)
2,500 sf

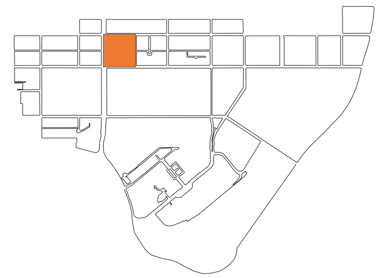
POTENTIAL SUBSURFACE INFILTRATION/DETENTION
- Shared Facility

EXISTING TREES
- Potential Credit

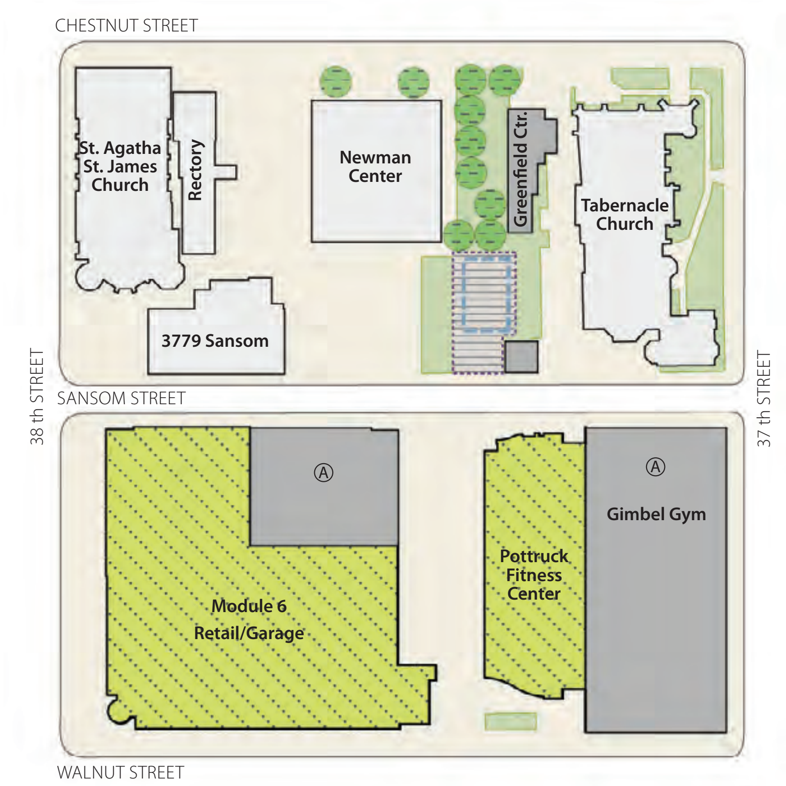
UNIVERSITY OWNED BUILDING
- No green roof proposed

NON - PENN OWNED BUILDING

Ⓐ • Buildings less feasible for green roof retrofit



Block 4



POTENTIAL GREEN ROOF CONVERSION
- Pottruck 13,200 sf
- Module 6 34,900 sf

(Convert upper level of Module 6 to partial green roof. Loss of approximately 84 parking spaces.)

POTENTIAL BIORETENTION AREA
- In exsiting grass area

POTENTIAL SUBSURFACE INFILTRATION/DETENTION
- Shared Facility

EXISTING GREEN SPACE

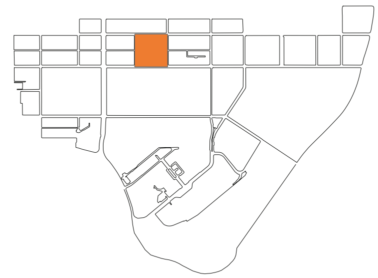
EXISTING TREE
- Potential Credit

EXISTING PAVEMENT
- Potential Disconnection Credit

UNIVERSITY OWNED BUILDING
- No green roof proposed

NON - PENN OWNED BUILDING

Ⓐ • Buildings less feasible for green roof retrofit



Block 5

POTENTIAL GREEN ROOF CONVERSION

- Sansom Place West 2,420 sf
- Sansom Place East 5,600 sf
- ICA 12,700 sf
- Retail 1 5,380 sf
- Retail 2 15,510 sf

EXISTING GREEN ROOF

POTENTIAL BIORETENTION AREA

- To manage parking lot

POTENTIAL SUBSURFACE INFILTRATION/DETENTION

- To manage pavement/roof

EXISTING GREEN SPACE

EXISTING TREE

- Potential Credit

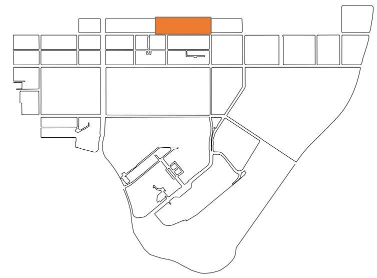
EXISTING PAVEMENT

- Potential Disconnection Credit

UNIVERSITY OWNED BUILDING

- No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit



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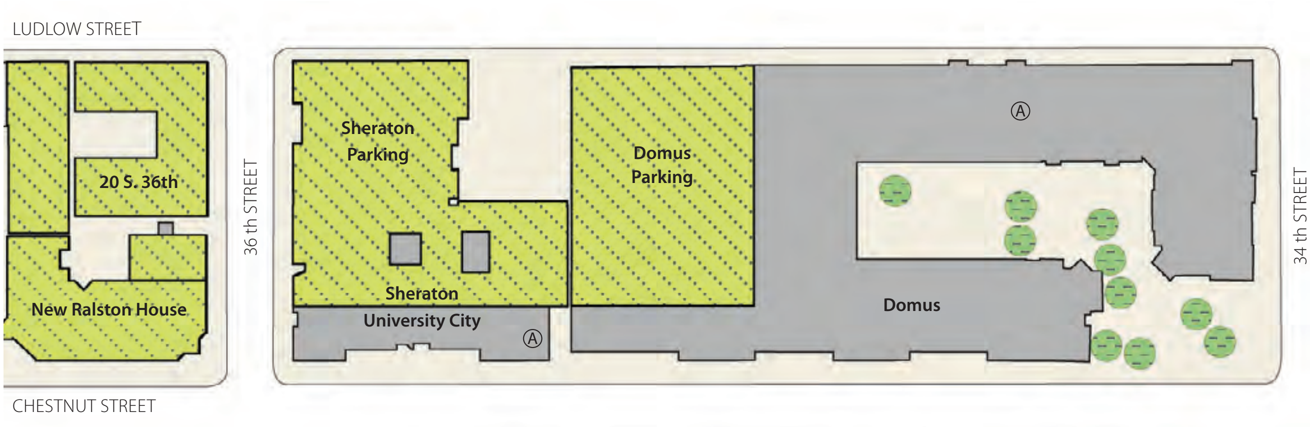


POTENTIAL GREEN ROOF CONVERSION

- 20 S. 36th 8,800 sf
- New Ralston House 18,350 sf
- Sheraton Parking 12,500 sf
  (Conversion of upper level of garage to green roof. Loss of approximately 39 parking spaces.)
- Sheraton Univ. City 10,600 sf
- Domus Parking 20,680 sf
  (Conversion of upper level of garage to green roof. Loss of approximately 58 parking spaces.)

EXISTING TREE

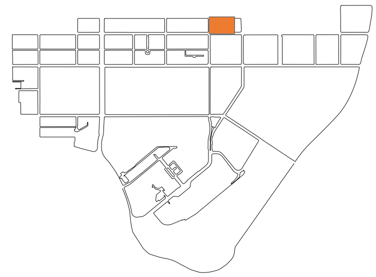
- Potential Credit

UNIVERSITY OWNED BUILDING

- No green roof proposed

Ⓐ

- Buildings less feasible for green roof retrofit



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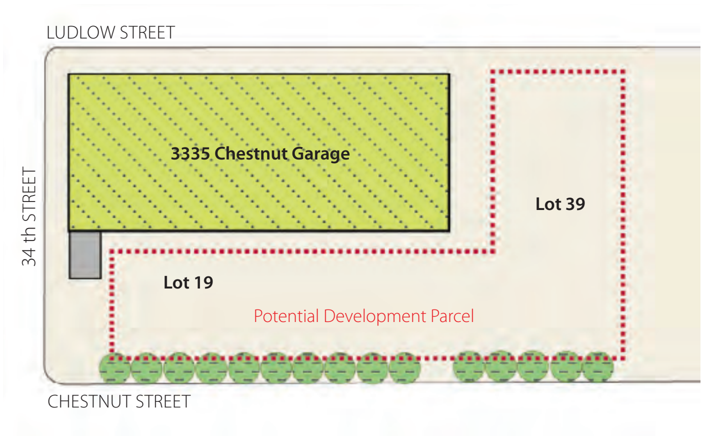
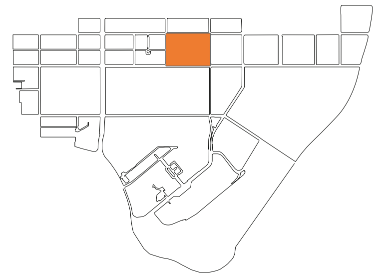


POTENTIAL GREEN ROOF CONVERSION
• 3335 Chestnut 31,800 sf
(Conversion of upper level of garage to green roof. Loss of approximately 91 parking spaces. This building is slated for renovations per "PENN CONNECTS".)

EXISTING TREE
• Potential Credit

PENN CONNECTS/POTENTIAL DEVELOPMENT
• 34th and Chestnut - Mixed Use
• Potential green roof

UNIVERSITY OWNED BUILDING
• No green roof proposed



Block 8

POTENTIAL GREEN ROOF CONVERSION
- Kings Court 12,700 sf
- Tanenbaum Hall 16,600 sf
- Gittis Hall 11,500 sf
- 133 S. 36th 6,420 sf
- Franklin Annex 19,500 sf
- 3401 Walnut 43,930 sf

EXISTING GREEN ROOF
- Golkin Hall 7,210 sf
- English House 11,520 sf

EXISTING POROUS PAVEMENT
- Golkin Hall 7,420 sf

POTENTIAL BIORETENTION AREA
- In existing grass area to manage roofs

EXISTING GREEN SPACE

EXISTING TREE
- Potential Credit

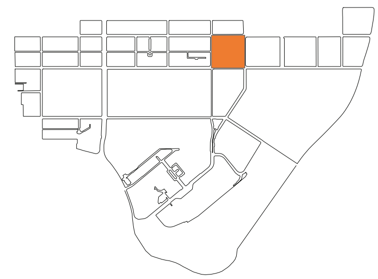
EXISTING PAVEMENT
- Potential Disconnection

PENN CONNECTS/POTENTIAL DEVELOPMENT
- Potential green roof

UNIVERSITY OWNED BUILDING
- No green roof proposed

Ⓐ
- Buildings less feasible for green roof retrofit

Block 9



POTENTIAL GREEN ROOF CONVERSION
- Hill House 37,640 sf
  (This building is slated for renovations per "*PENN CONNECTS*")

POROUS PAVEMENT CONVERSION
8,340 sf

POTENTIAL BIORETENTION AREA
- In existing grass area to manage pavements and/or roofs.

POTENTIAL SUBSURFACE INFILTRATION/DETENTION
- For new building

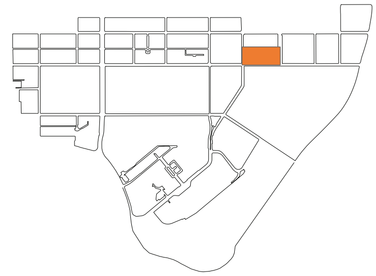
EXISTING GREEN SPACE

EXISTING TREE CREDITS
- PWD Approved - 8/2011
  11,178 sf

PENN CONNECTS/POTENTIAL DEVELOPMENT
- Potential green roof

UNIVERSITY OWNED BUILDING
- No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit



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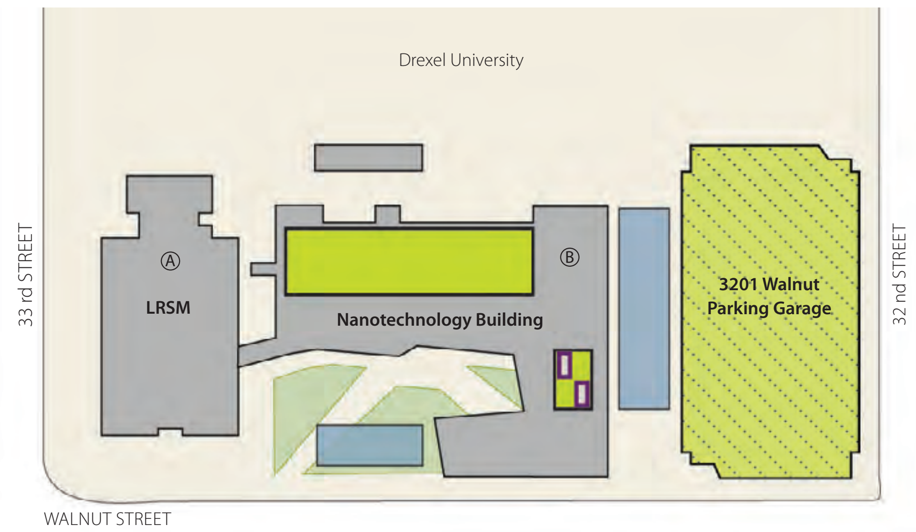


POTENTIAL GREEN ROOF CONVERSION
• 3201 Walnut 29,900 sf
(Conversion of upper level of garage to green roof. Loss of approximately 86 parking spaces.)

EXISTING GREEN ROOF
• Nanotechnology 8,300 sf

EXISTING BIORETENTION AREA
• Nanotechnology - 2,400 sf managed

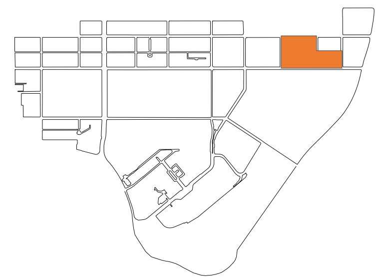
EXISTING SUBSURFACE INFILTRATION/DETENTION
• Nanotechnology - 49,070 sf managed

EXISTING GREEN SPACE

UNIVERSITY OWNED BUILDING
• No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit

Ⓑ • Existing roof disconnections: Nanotechnology - 3,982 sf



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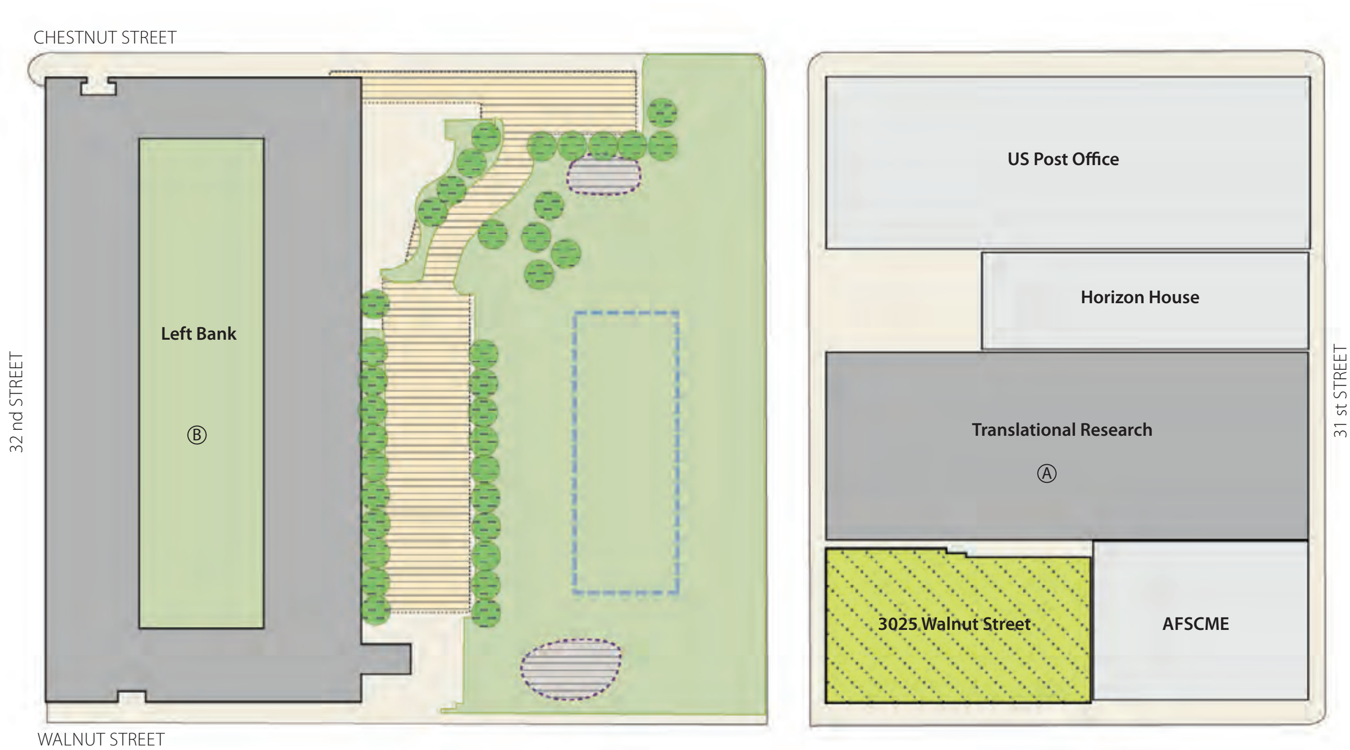


POTENTIAL GREEN ROOF CONVERSION
- 3025 Walnut 19,080 sf
- Left Bank 24,630 sf

(Mechanical equipment and towers limit space for green roof conversion.)

POROUS PAVEMENT CONVERSION
25,570sf

POTENTIAL BIORETENTION AREA
- In existing grass area to manage parking areas, allow field to remain.

POTENTIAL SUBSURFACE INFILTRATION/DETENTION
- Shared facility - parking, driveway, 3025 Walnut and Apparatus Buildings

EXISTING GREEN SPACE

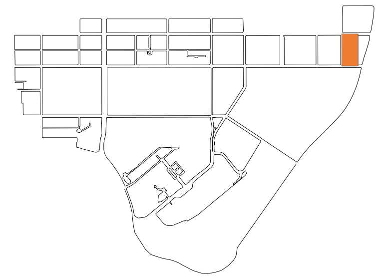
EXISTING TREE
- Potential Credit

UNIVERSITY OWNED BUILDING
- No green roof proposed

NON - PENN OWNED BUILDING

Ⓐ • Buildings less feasible for green roof retrofit

Ⓑ • Interior courtyard



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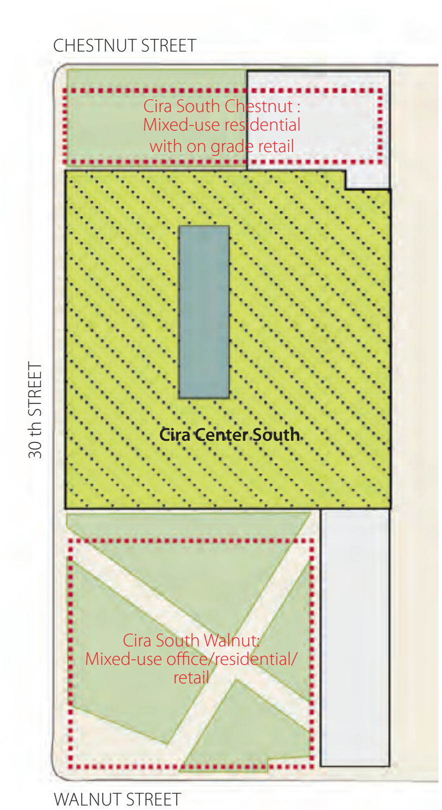
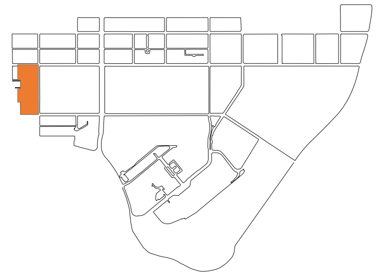


- POTENTIAL GREEN ROOF CONVERSION
  - Cira Center South 53,850 sf
- EXISTING SUBSURFACE INFILTRATION/DETENTION
  - Managed 53,850 sf
- EXISTING GREEN SPACE
- PENN CONNECTS/POTENTIAL DEVELOPMENT
  - Future Buildings
  - Potential green roof
- NON - PENN OWNED BUILDING



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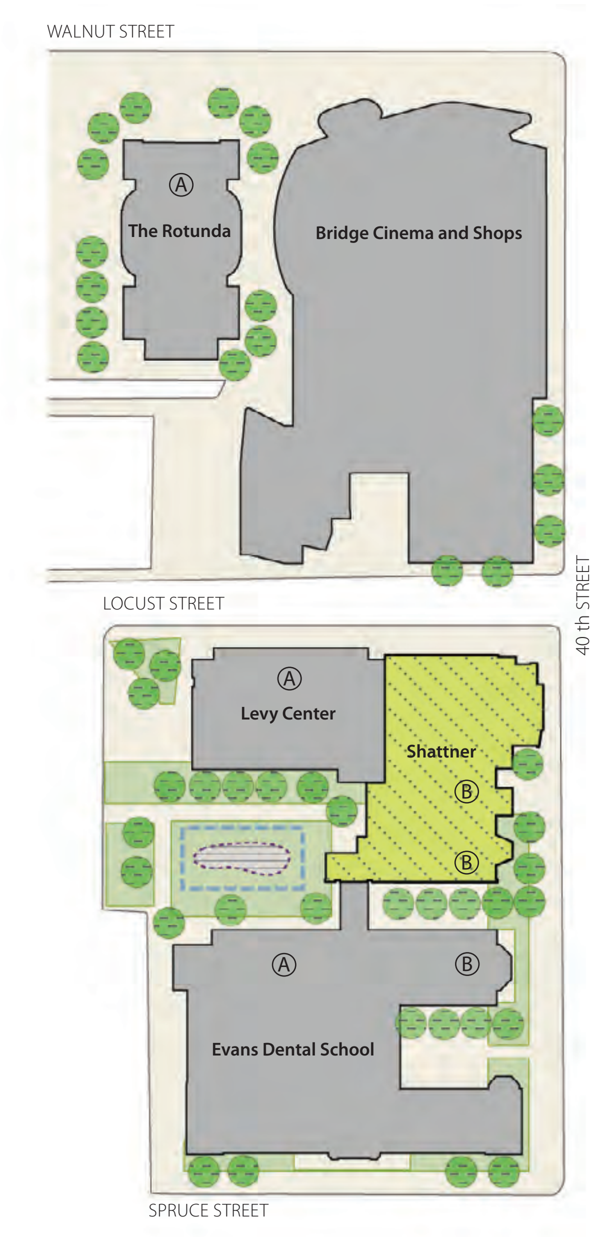


POTENTIAL GREEN ROOF CONVERSION
- Levy/Schattner 17,000 sf

POTENTIAL BIORETENTION AREA
- To manage roof

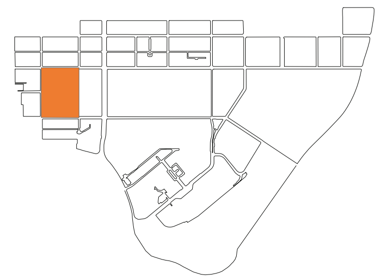
POTENTIAL SUBSURFACE INFILTRATION/DETENTION
- To manage roof

EXISTING TREE
- Potential Credit

UNIVERSITY OWNED BUILDING
- No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit

Ⓑ • Buildings slated for renovation per "*PENN CONNECTS*"



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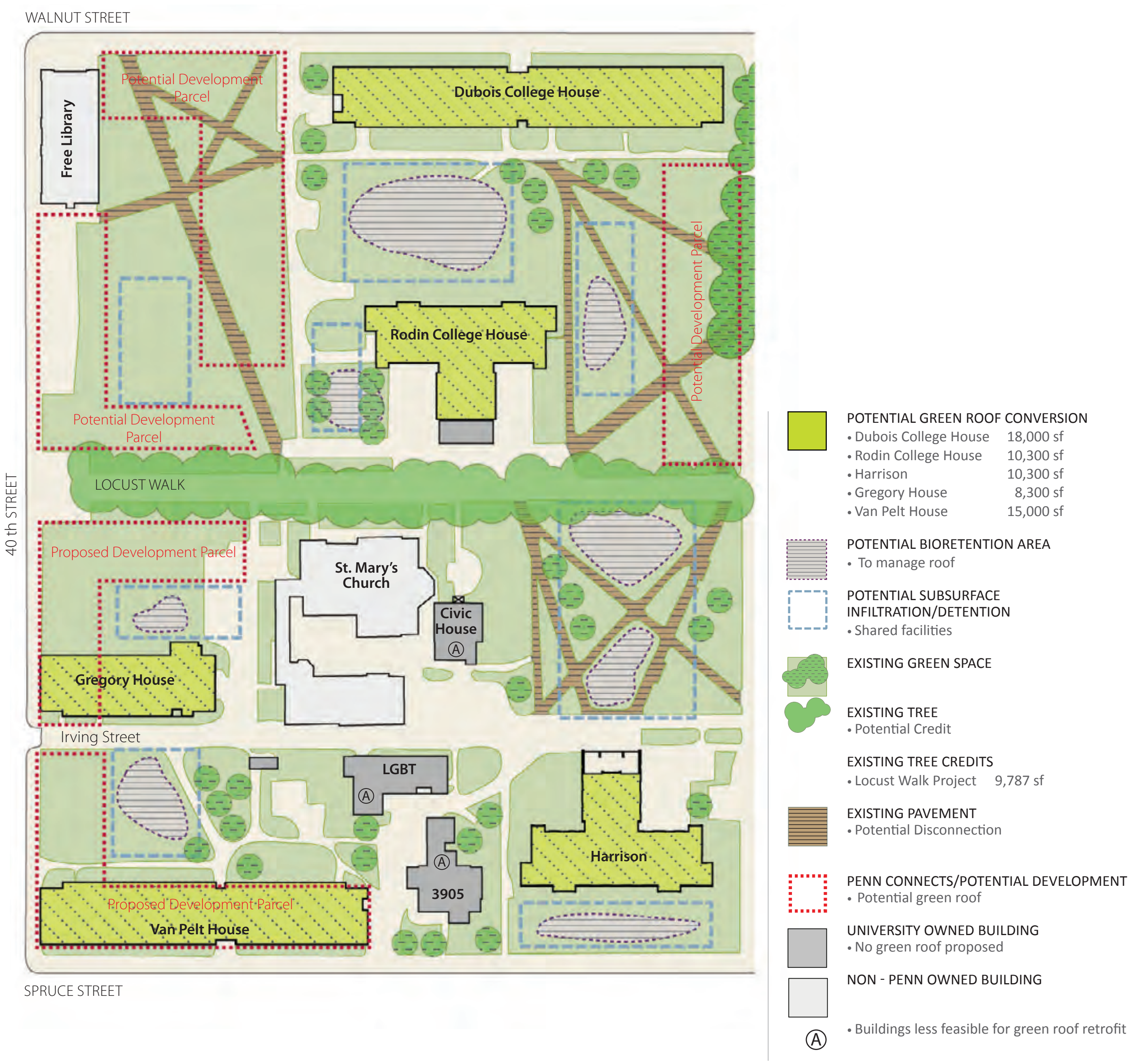
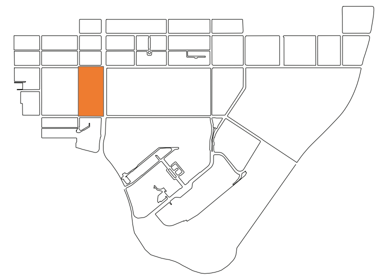

WALNUT STREET
40 th STREET
SPRUCE STREET
LOCUST WALK
Irving Street
Free Library
Potential Development Parcel
Dubois College House
Rodin College House
Potential Development Parcel
Potential Development Parcel
Proposed Development Parcel
St. Mary's Church
Civic House
Gregory House
LGBT
3905
Harrison
Proposed Development Parcel
Van Pelt House
POTENTIAL GREEN ROOF CONVERSION
• Dubois College House 18,000 sf
• Rodin College House 10,300 sf
• Harrison 10,300 sf
• Gregory House 8,300 sf
• Van Pelt House 15,000 sf
POTENTIAL BIORETENTION AREA
• To manage roof
POTENTIAL SUBSURFACE INFILTRATION/DETENTION
• Shared facilities
EXISTING GREEN SPACE
EXISTING TREE
• Potential Credit
EXISTING TREE CREDITS
• Locust Walk Project 9,787 sf
EXISTING PAVEMENT
• Potential Disconnection
PENN CONNECTS/POTENTIAL DEVELOPMENT
• Potential green roof
UNIVERSITY OWNED BUILDING
• No green roof proposed
NON - PENN OWNED BUILDING
• Buildings less feasible for green roof retrofit



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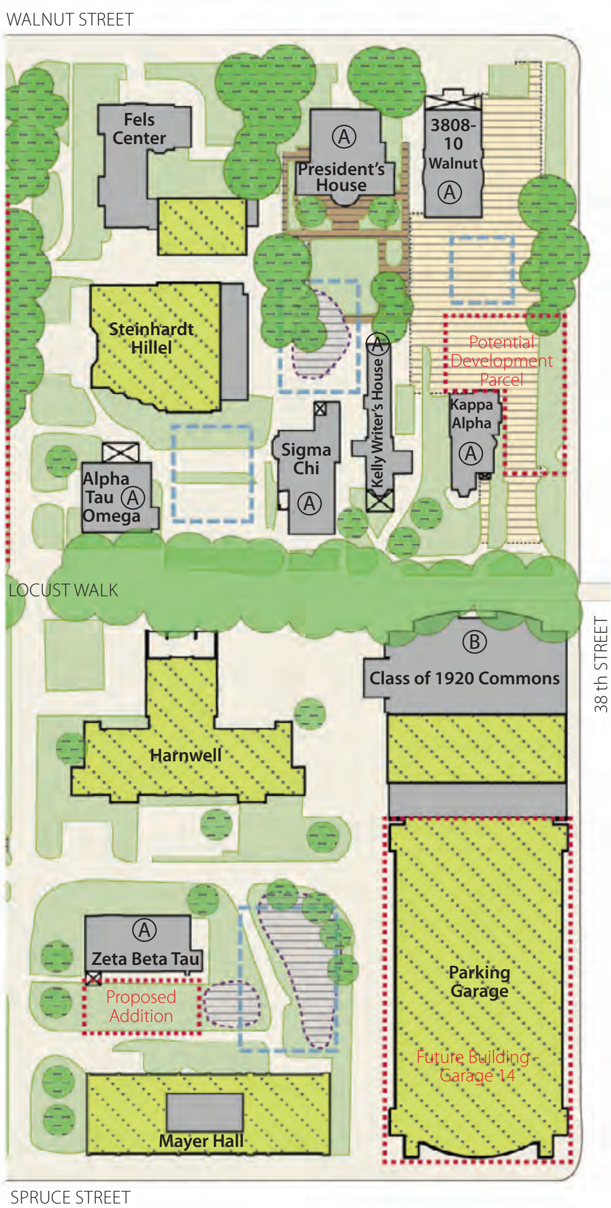


POTENTIAL GREEN ROOF CONVERSION

- Fels Center 2,530 sf
- Steinhardt Hall 7,940 sf
- Harnwell 11,400sf
- 1920 Commons 6,300 sf
- Mayer Hall 8,500 sf
- Parking Garage 30,000 sf

(Loss of approx. 90 parking spaces.)

POROUS PAVEMENT CONVERSION
16,450 sf

POTENTIAL BIORETENTION AREA
- To manage pavement and/or roofs

POTENTIAL SUBSURFACE INFILTRATION/DETENTION
- To manage pavement and/or roofs

EXISTING GREEN SPACE

EXISTING TREE
- Potential Credit

EXISTING TREE CREDITS
- Locust Walk Project 6,487 sf

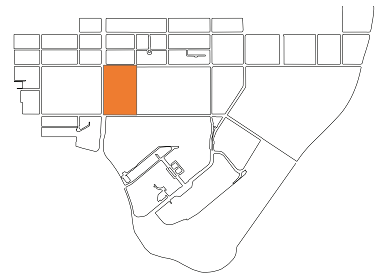
EXISTING PAVEMENT
- Potential Disconnection

PENN CONNECTS/POTENTIAL DEVELOPMENT
- Potential green roof

UNIVERSITY OWNED BUILDING
- No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit

Ⓑ • Buildings slated for renovation per "*PENN CONNECTS*"



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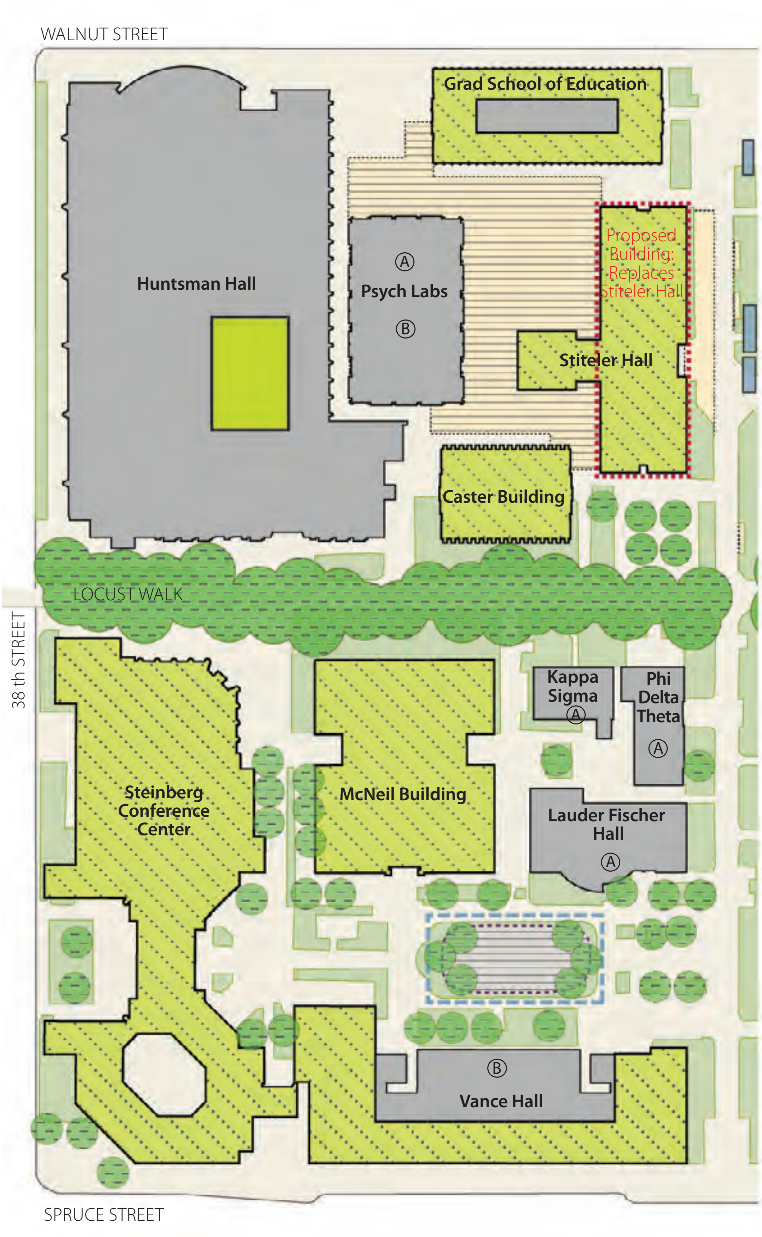


POTENTIAL GREEN ROOF CONVERSION
- Grad School of Edu 7,500 sf
- Stitler Hall 14,000 sf
- Caster 6,120 sf
- Steinberg 34,700 sf
- McNeil 19,000 sf
- Vance 12,950 sf

EXISTING GREEN ROOF
- Huntsman Hall 4,125 sf

POROUS PAVEMENT CONVERSION 18,190 sf

EXISTING POROUS PAVEMENT
- Class of 62 Walk 4,200 sf

POTENTIAL BIORETENTION AREA
- To manage roofs

POTENTIAL SUBSURFACE INFILTRATION/DETENTION
- To manage pavement and/or roofs

EXISTING SUBSURFACE INFILTRATION/DETENTION

EXISTING GREEN SPACE

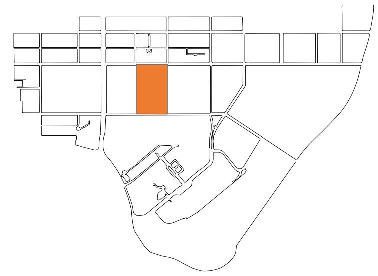
EXISTING TREE
- Potential Credit

PENN CONNECTS/POTENTIAL DEVELOPMENT
- Potential green roof

UNIVERSITY OWNED BUILDING
- No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit

Ⓑ • Buildings slated for renovation per "*PENN CONNECTS*"



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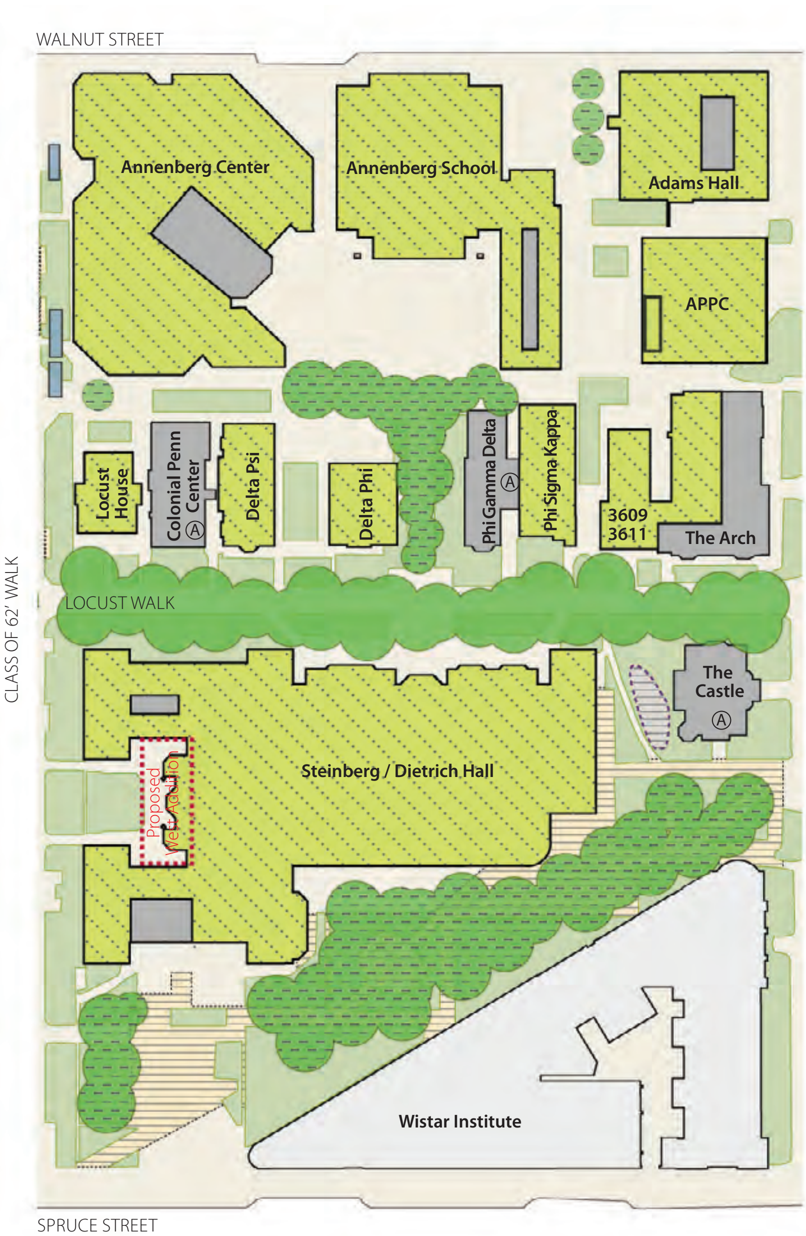


POTENTIAL GREEN ROOF CONVERSION
- Annenberg Center 27,300 sf
- Annenberg School 18,750 sf
  (Partial conversion -multiple levels)
- Adams Hall 7,250 sf
  (Partial conversion)
- APPC 6,050 sf
- Locust House 2,300 sf
- Delta Psi 3,350 sf
- Delta Phi 2,600 sf
- Phi Signa Kappa 3,800 sf
- 3609/3611 2,950 sf
- The Arch 3,700 sf
  (Partial conversion)
- Steinberg/Dietrich 55,250 sf

POROUS PAVEMENT CONVERSION
26,000 sf

EXISTING POROUS PAVEMENT

POTENTIAL SUBSURFACE INFILTRATION/DETENTION
- To manage pavement and/or roofs.

EXISTING SUBSURFACE INFILTRATION/DETENTION
- Manages 7,094 sf

EXISTING GREEN SPACE

EXISTING TREE
- Potential Credit

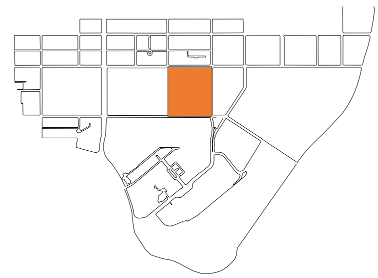
EXISTING TREE CREDITS
- Locust Walk Project 12,749 sf

PENN CONNECTS/POTENTIAL DEVELOPMENT
- Potential green roof

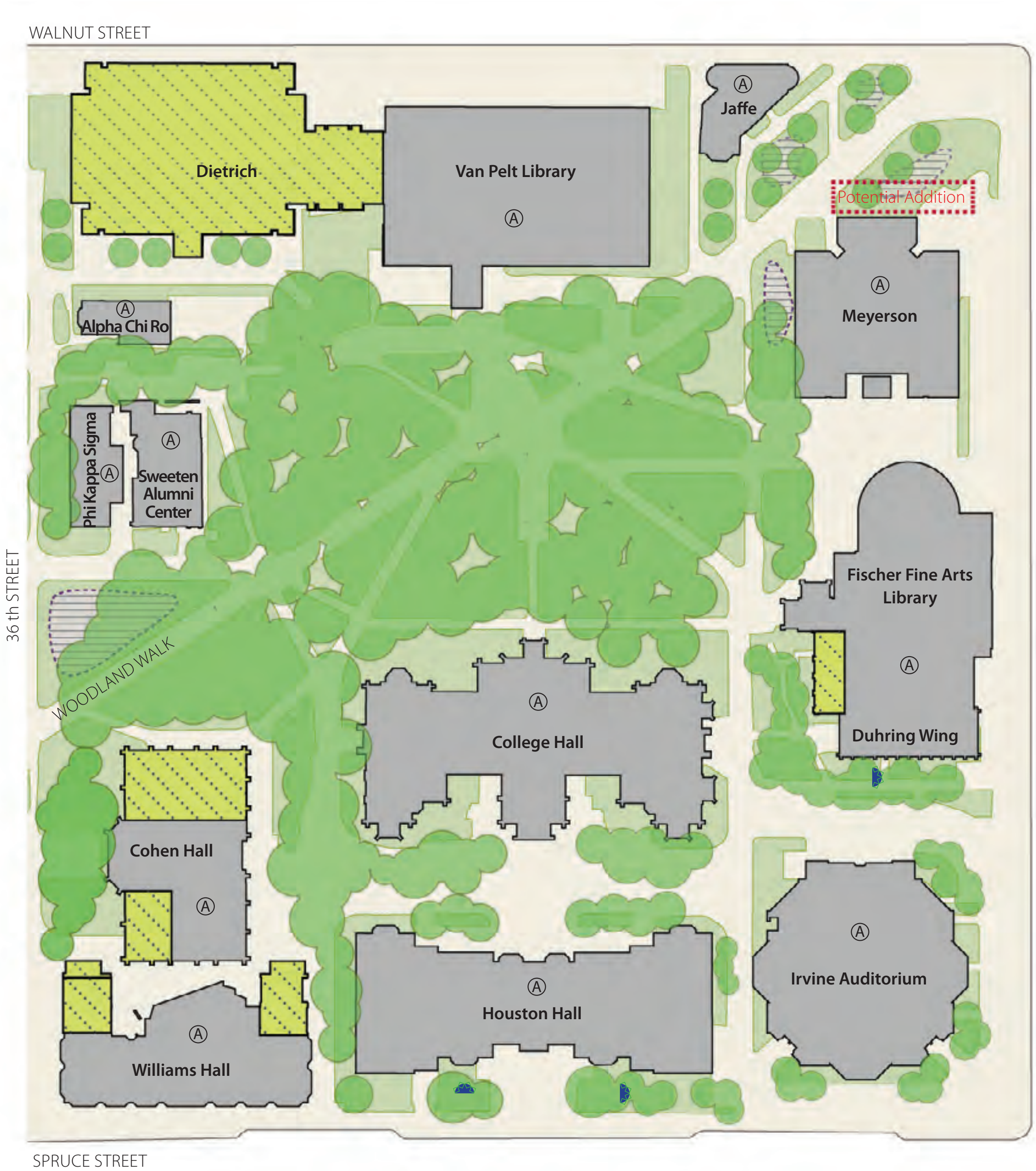
UNIVERSITY OWNED BUILDING
- No green roof proposed

NON - PENN OWNED BUILDING

Ⓐ
- Buildings less feasible for green roof retrofit



Block 18



POTENTIAL GREEN ROOF CONVERSION
- Van Pelt Library 25,950 sf
- Fischer Fine Arts 1,070 sf
- Cohen Hall 6,705 sf
- Williams Hall 3,700 sf

(All partial conversions.)

POTENTIAL BIORETENTION AREA
- To manage roofs.

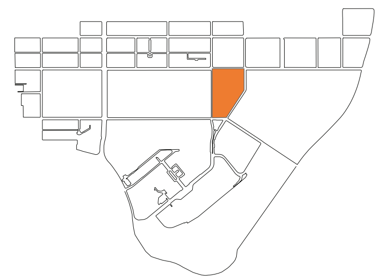
EXISTING GREEN SPACE

EXISTING TREE CREDITS
- PWD Approved 3/22/11
68,205 sf

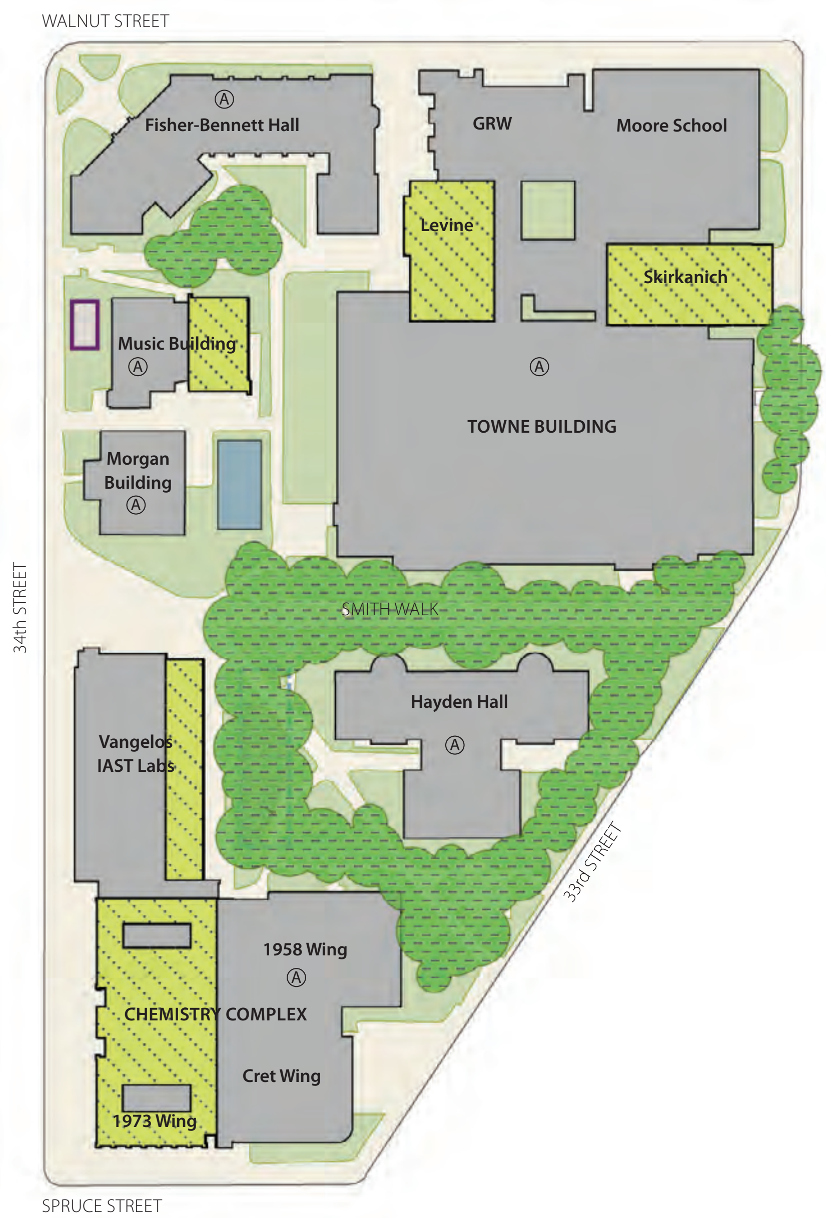
PENN CONNECTS/POTENTIAL DEVELOPMENT
- Potential green roof

UNIVERSITY OWNED BUILDING
- No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit



Block 19



POTENTIAL GREEN ROOF CONVERSION
- Levine 5,500 sf *(Partial conversion)*
- Skirkanich 3,890 sf *(Partial conversion)*
- Music Building 2,880 sf
- Vagelos IAST Labs 4,260 sf *(Partial conversion)*
- Chemistry Complex 12,900 sf *(Partial conversion)*

EXISTING BIORETENTION AREA
- To manage pavement for Music Building Addition.

POTENTIAL SUBSURFACE INFILTRATION/DETENTION

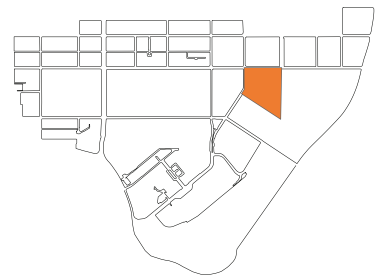
EXISTING SUBSURFACE INFILTRATION/DETENTION
- Music Building Addition 6,343 sf managed

EXISTING GREEN SPACE

EXISTING TREE
- Potential Credit

UNIVERSITY OWNED BUILDING
- No green roof proposed

Ⓐ
- Buildings less feasible for green roof retrofit



Block 20

POTENTIAL GREEN ROOF CONVERSION
- Rittenhouse Labs 57,300 sf (Partial conversion)
- Palestra 47,500 sf
- Hutchinson Gym 14,200 sf *(Partial conversion)*

POROUS PAVEMENT CONVERSION
27,800 sf

EXISTING POROUS PAVEMENT
- George Weiss Pavilion Project. 26,970 sf

EXISTING BIORETENTION AREA
- Shoemaker Green 21,653 sf managed

EXISTING SUBSURFACE INFILTRATION/DETENTION
- Manages Shoemaker Green. 9,340 sf managed. *(20,000 gallon capacity also includes condensate from Hutchinson Gym. No roofs attached.)*

EXISTING GREEN SPACE

EXISTING TREE CREDITS
- Shoemaker Green 16,222 sf

PENN CONNECTS/POTENTIAL DEVELOPMENT
- Potential green roof

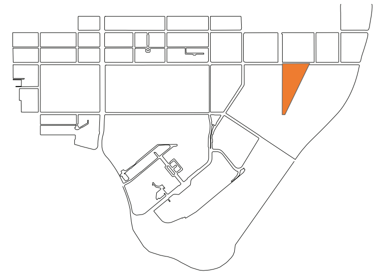
UNIVERSITY OWNED BUILDING
- No green roof proposed

Ⓑ
- Buildings slated for renovation per "*PENN CONNECTS*"

Ⓒ
- Buildings slated for conversion to green space per "*PENN CONNECTS*"
- Potential bioretention to manage roof

Ⓓ
- Existing 20,000 gallon Cistern under Shoemaker Green

CONDENSATE WATER LINE
- Connection from Hutchinson Gym to existing sub-surface detention



Block 21

POTENTIAL GREEN ROOF CONVERSION
• 1923 Ice Rink 46,000 sf

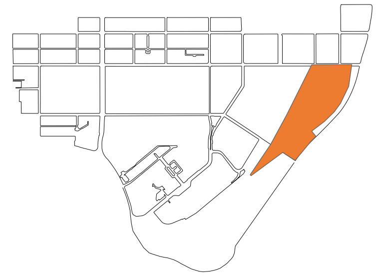
POROUS PAVEMENT CONVERSION
57,800 sf

POTENTIAL SUBSURFACE INFILTRATION/DETENTION
• 1923 Ice Rink 46,000 sf

EXISTING GREEN SPACE

UNIVERSITY OWNED BUILDING
• No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit



Block 22

EXISTING BIORETENTION AREA
• Penn Park 115,366 sf managed

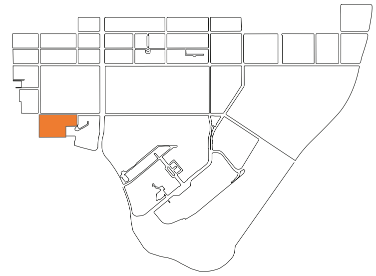
EXISTING SUBSURFACE INFILTRATION/DETENTION
• Penn Park 346,366 sf managed

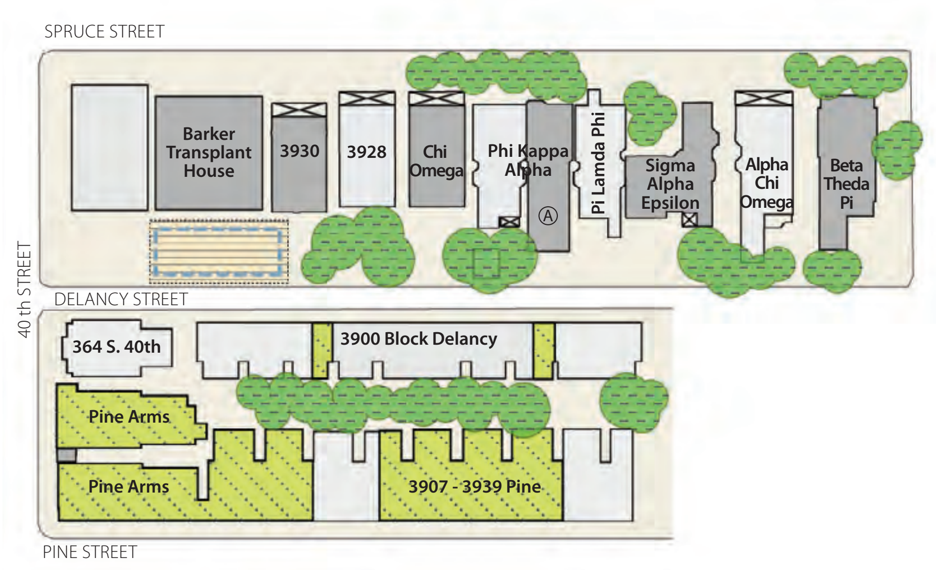
EXISTING GREEN SPACE

EXISTING PAVEMENT
• Penn Park 26,530 sf managed

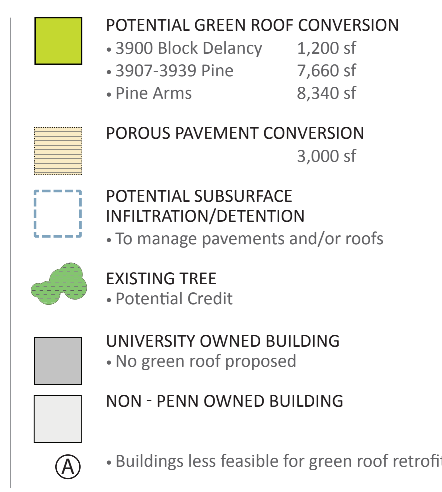
UNIVERSITY OWNED BUILDING
• No green roof proposed

Block 23

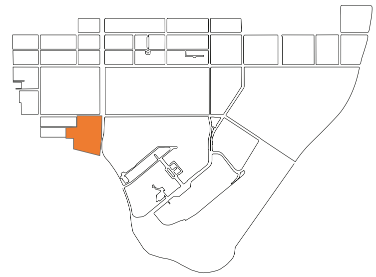




SPRUCE STREET
Barker Transplant House
3930
3928
Chi Omega
Phi Kappa Alpha
Pi Lamda Phi
Sigma Alpha Epsilon
Alpha Chi Omega
Beta Theda Pi
40 th STREET
DELANCY STREET
364 S. 40th
3900 Block Delancy
Pine Arms
Pine Arms
3907 - 3939 Pine
PINE STREET



POTENTIAL GREEN ROOF CONVERSION
• 3900 Block Delancy 1,200 sf
• 3907-3939 Pine 7,660 sf
• Pine Arms 8,340 sf
POROUS PAVEMENT CONVERSION
3,000 sf
POTENTIAL SUBSURFACE INFILTRATION/DETENTION
• To manage pavements and/or roofs
EXISTING TREE
• Potential Credit
UNIVERSITY OWNED BUILDING
• No green roof proposed
NON - PENN OWNED BUILDING
• Buildings less feasible for green roof retrofit



Block 24

POTENTIAL GREEN ROOF CONVERSION
- Rosenthal 13,300 sf
  (Partial conversion)
- Veterinary Hospital 16,800 sf
  (Partial conversion)
- Hill Pavilion 14,600 sf
  (Partial conversion)

POROUS PAVEMENT CONVERSION
19,750 sf

POTENTIAL BIORETENTION AREA
- To manage pavements and/or roofs

EXISTING GREEN SPACE

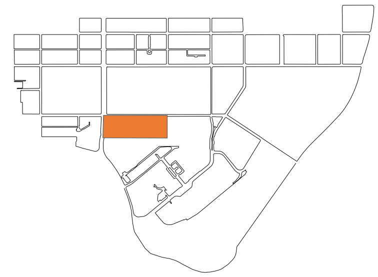
EXISTING TREE
- Potential Credit

PENN CONNECTS/POTENTIAL DEVELOPMENT
- Potential green roof

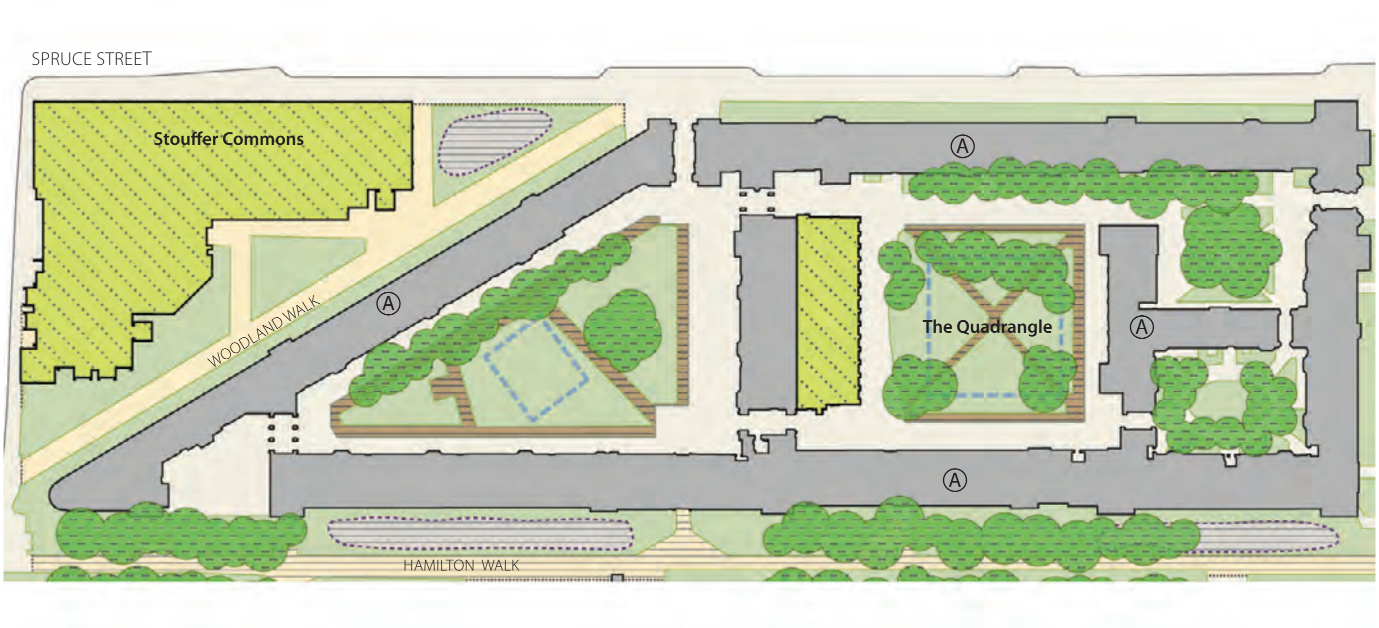
UNIVERSITY OWNED BUILDING
- No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit

Ⓑ • Buildings slated for renovation per "*PENN CONNECTS*", Ryan Hospital Renovations.



Block 25



POTENTIAL GREEN ROOF CONVERSION
- Stouffer Triangle 36,900 sf
  (Partial conversion)
- Quad 6,500 sf

POROUS PAVEMENT CONVERSION

EXISTING POROUS PAVEMENT
- Woodland Walk 11,180 sf

POTENTIAL BIORETENTION AREA
- To manage roof and walkway

POTENTIAL SUBSURFACE INFILTRATION/DETENTION
- To manage roof and walkway

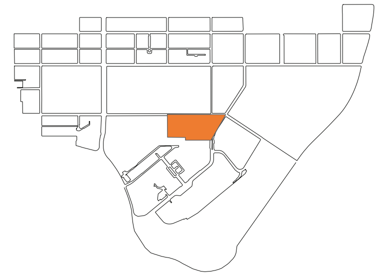
EXISTING GREEN SPACE

EXISTING TREE
- Potential Credit

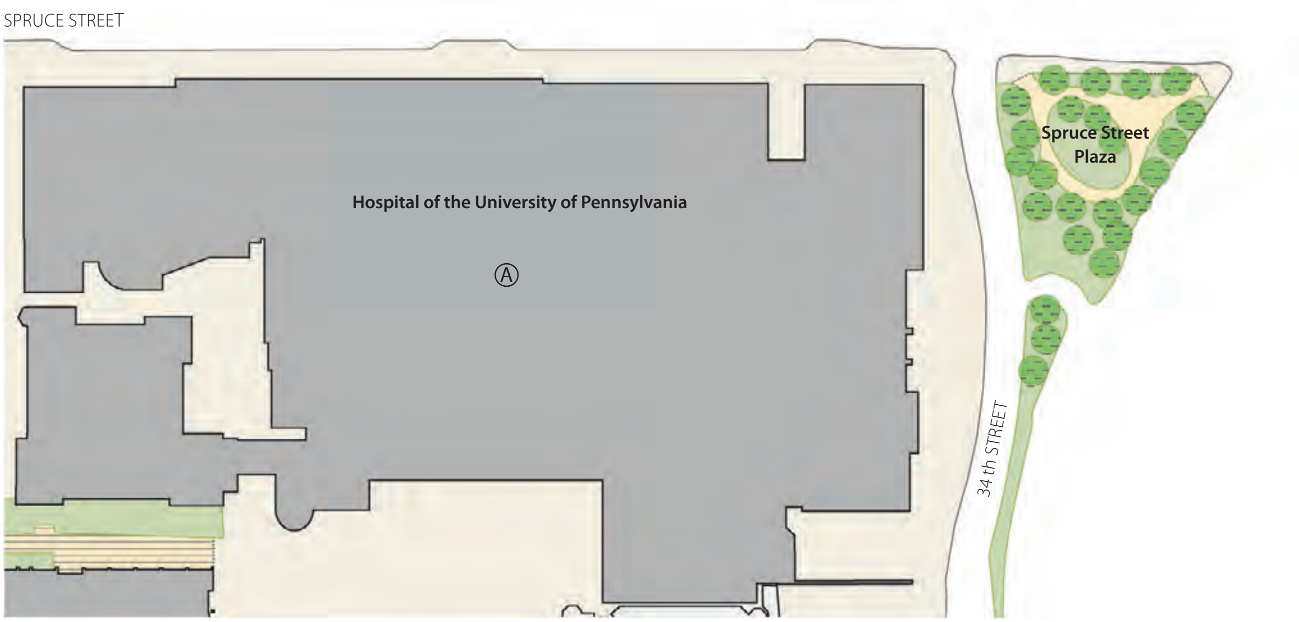
EXISTING PAVEMENT
- Potential Disconnection

UNIVERSITY OWNED BUILDING
- No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit



Block 26



EXISTING POROUS PAVEMENT
3,950 sf

POROUS PAVEMENT CONVERSION

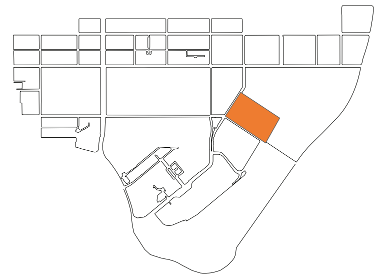
EXISTING GREEN SPACE

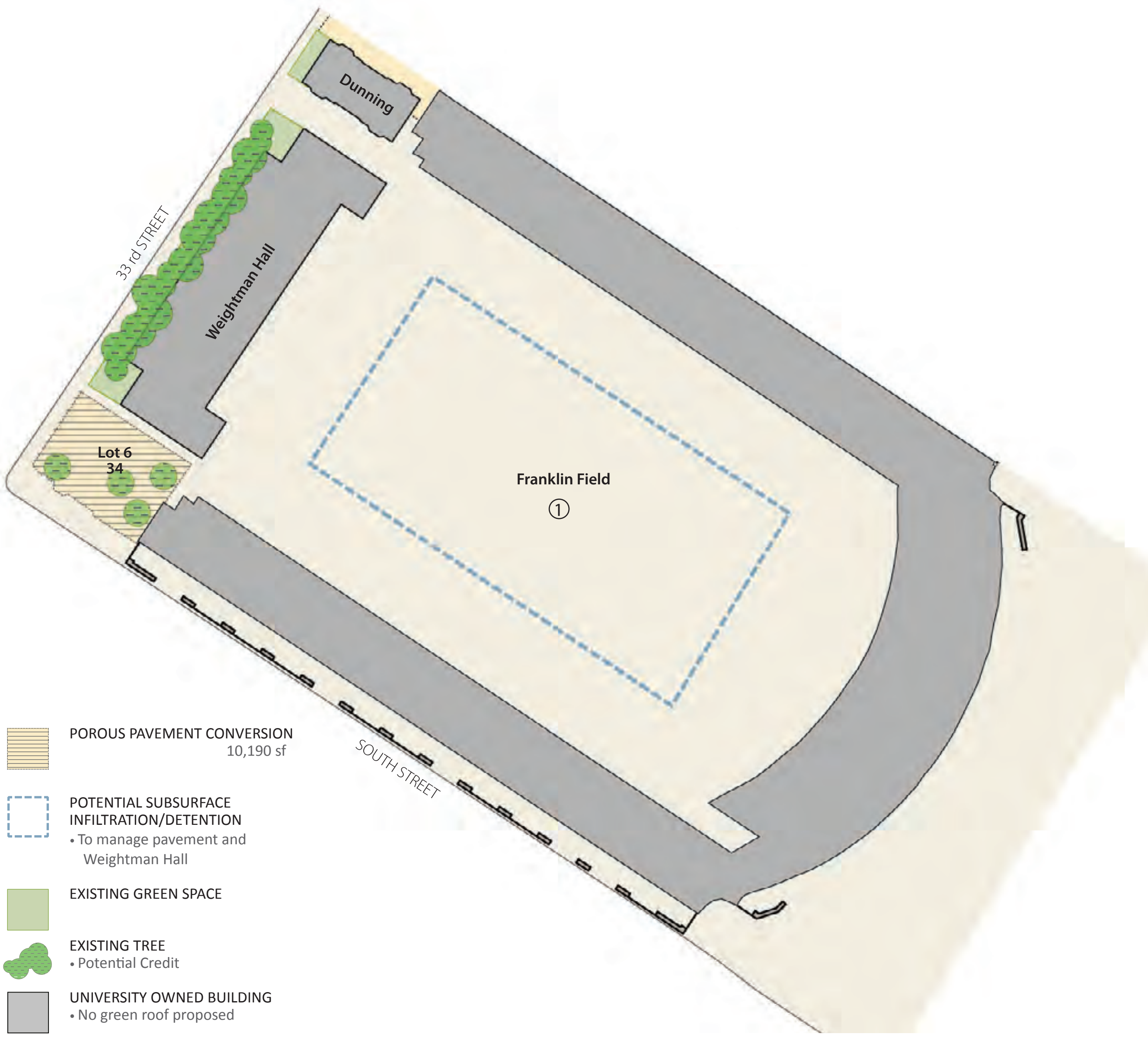
EXISTING TREE
• Potential Credit

UNIVERSITY OWNED BUILDING
• No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit

Block 27





POROUS PAVEMENT CONVERSION
10,190 sf

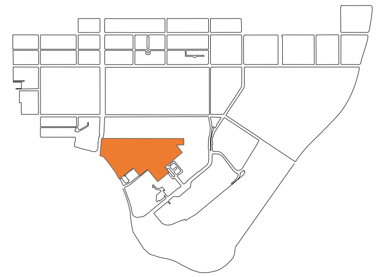
POTENTIAL SUBSURFACE INFILTRATION/DETENTION
• To manage pavement and Weightman Hall

EXISTING GREEN SPACE

EXISTING TREE
• Potential Credit

UNIVERSITY OWNED BUILDING
• No green roof proposed

① • During future improvements, install Subsurface Infiltration/Detention below field to manage bleachers and artificial turf.



Block 28

POTENTIAL GREEN ROOF CONVERSION
- Clinical Research 23,200 sf
- BRB11 9,040 sf
  (Partial conversion)

EXISTING GREEN ROOF
- Fagin Hall

EXISTING GREEN SPACE

EXISTING TREE
- Potential Credit

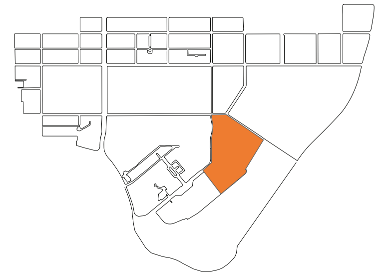
PENN CONNECTS/POTENTIAL DEVELOPMENT
- Future Neural-Behavioral Sciences Building.
- Potential green roof

UNIVERSITY OWNED BUILDING
- No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit

Ⓑ • Buildings slated for renovation per "*PENN CONNECTS*", Fagin Hall and Stemmler Hall

Ⓒ • Mudd Labs building slated for demolition per "*PENN CONNECTS*"



Block 29

POTENTIAL GREEN ROOF CONVERSION
- University Museum Parking Garage 41,170 sf
  (Convert upper level of garage to green roof. Loss of approximately 52 parking spaces.)
- Garage 36 51,400 sf
  (Convert upper level of garage to green roof. Loss of approximately 140 parking spaces.)
- Perleman Center 71,000 sf
  (*Partial conversion)*

EXISTING GREEN ROOF
- PCAM Canopy 2,000 sf

EXISTING GREEN SPACE

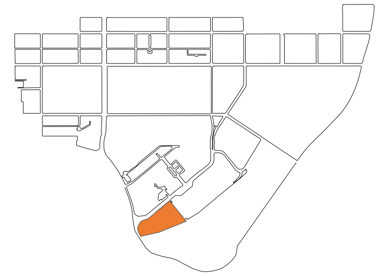
EXISTING TREE
- Potential Credit

PENN CONNECTS/POTENTIAL DEVELOPMENT
- Potential green roof

UNIVERSITY OWNED BUILDING
- No green roof proposed

Ⓐ • Buildings less feasible for green roof retrofit

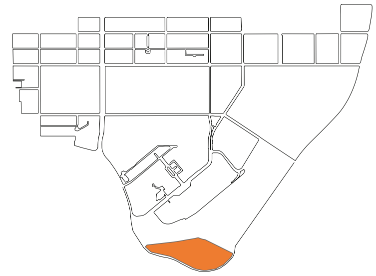
Block 30



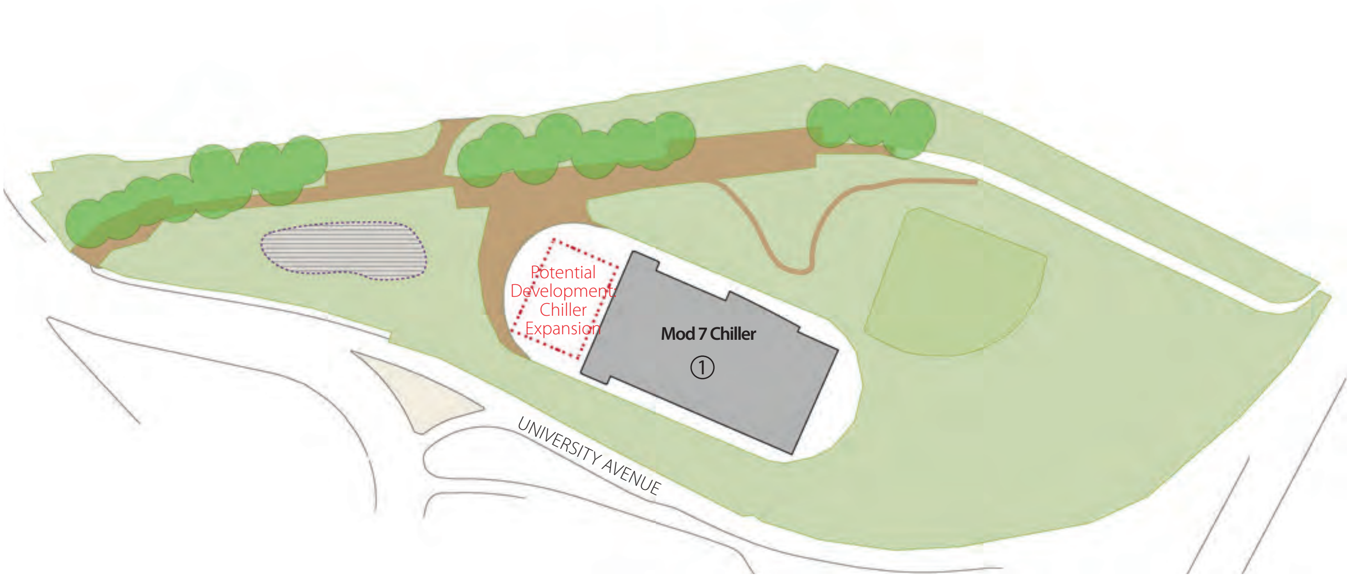
POTENTIAL GREEN ROOF CONVERSION
- Garage 68,300 sf
  (Convert upper level of garage to green roof. Loss of approximately 188 parking spaces.)

EXISTING GREEN SPACE

PENN CONNECTS/POTENTIAL DEVELOPMENT
- Future Building - PA Hall Site Redevelopment
- Potential green roof



Block 31



POTENTIAL BIORETENTION AREA
- To manage pavement and roofs.

EXISTING GREEN SPACE

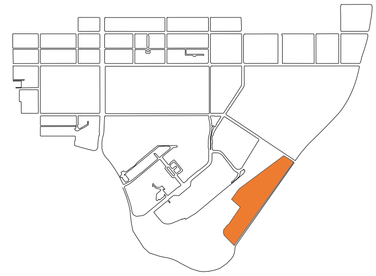
EXISTING TREE CREDITS
- PWD Approved Credit 14,630 sf

EXISTING PAVEMENT
- PWD Approved Disconnection Credit 8,800 sf

PENN CONNECTS/POTENTIAL DEVELOPMENT
- Potential green roof

UNIVERSITY OWNED BUILDING
- No green roof proposed

(1)
- Mod 7 Chiller. Existing credit for cooling tower water re-use 15,900 sf



Block 32

POTENTIAL BIORETENTION AREA
- To manage pavement and roofs.

EXISTING GREEN SPACE

PENN CONNECTS/POTENTIAL DEVELOPMENT
- Potential green roof

UNIVERSITY OWNED BUILDING
- No green roof proposed

STORMWATER MANAGEMENT COSTS AND PWD FEES

This section provides information on typical construction costs for the various sustainable stormwater management practices. The approximate cost ranges (in 2012 dollars) for each type of practice were developed from Duffield Associate's project experience; discussions with engineers, architects, landscape architects, contractors, and manufacturer's representatives; and various online resources.

The stormwater management construction costs are provided on a per square foot basis. This allows for relative cost comparisons for different practices shown for the areas on the block-by-block graphics. It should be noted that this does not necessarily provide an accurate comparison with respect to the stormwater volume (cubic feet) that a given practice can manage per square foot of area. For example, an extensive green roof and porous pavement may each be designed to manage one inch of runoff per square foot of area, so these two practices are comparable on a cost per square foot basis. However, a bioretention area may be several feet in depth, so that it can store significantly more water per square foot of system than the green roof or porous pavement systems.

Ultimately, the PWD stormwater regulations will dictate what level of stormwater management is required for a given project (e.g., water quality only vs. full flood control), the site design will determine what practices may provide the required regulatory compliance (e.g., green roof on a proposed building and/or porous pavement for a proposed parking area), and then site constraints will largely determine which of those practices will work on the site (e.g., soil characteristics limiting infiltration may preclude the use of porous pavement).

Materials and delivery costs for stormwater management practices can also fluctuate, (typically upward) depending on multiple factors such as the price of oil. Some practices rely on plastic components, others on bituminous (asphalt) components, and all require delivery from the manufacturer's source to the installation site on campus.

Following the summary of typical construction costs, the PWD stormwater fee structure is described. Retrofitting existing construction to comply with the current regulations may result in a reduction in the stormwater fee for a given parcel, and therefore may provide a return on the investment in the retrofitting construction costs. However, as will be shown by examples, an adequate return on investment period may be many years due to the fee structure.

Stormwater Management Practice Construction Costs

A range of construction costs are provided for each stormwater management practice. For each practice, there may be associated benefits that reduce other construction costs or that provide other monetary benefits to the University. The value of these benefits are difficult to quantify due to the infinite variety in potential site layout designs and the mix of stormwater management practices that might be employed on a single site.

Green Roofs

Green roofs are typically more expensive than conventional roofs not only because of the required growing medium and plantings, but because the building's roof structure may require more structural strength to support the load of the green roof materials and the captured rainfall. The typical costs below represent just the roof membrane and the green roof drainage components, growing medium, and plantings.

- *Extensive green roof (typical 3-inch thick growing medium): $8-15/sf*
- *Intensive green roof (typical 1-foot thick (or greater) growing medium): $25-30/sf*
- *Tray-system green roof (typical 3-inch thick growing medium): $17-20/sf.*
- *Conventional roof for comparison (new membrane only): $7-10/sf*

The following factors may reduce the life cycle cost of a green roof system:

- *Longer roof life due to protection of the roof membrane from ultraviolet rays,*
- *Reduced heating and cooling costs due to growing medium acting as insulation,*
- *A green roof may allow a site to meet the 20% reduction in existing impervious area and exempt the site from the Flood Control requirement, thereby reducing stormwater management costs for large detention facilities and the associated larger piping needed to convey runoff to the systems,*
- *A green roof qualifies for a reduction in PWD stormwater fees.*

Porous Pavement

Porous asphalt and concrete are typically more expensive than conventional pavements. However, the use of porous pavement eliminates the storm inlets, piping, and subsurface stormwater management systems required for standard asphalt paved areas, so in certain situations the use of porous pavement may be a more economical choice. While the materials used in porous and conventional pavements are similar, increased pavement costs are associated with the more expensive stone subbase materials required for stormwater storage and the premium that may be paid for an asphalt plant to produce a small volume of a specialty blend of materials. Depending on the intended level of stormwater management in the pavement's stone subbase, the depth of stone will vary and affect the cost per square foot.

Mayfield Site Contractors, Inc., the firm involved in the Shoemaker Green project, provided the approximate cost information below. The costs represent the installed cost with site preparation, geotextile, subbase stone, choker course, and pavement. Mayfield indicated that these prices are relevant for Penn's campus-scale projects. As with most construction, the greater the quantity of material used, the lower the unit cost.

- *Porous asphalt (4" asphalt over 8" stone): $16/sf*
- *Conventional asphalt for comparison: $8/sf*
- *Porous concrete walkway (4" concrete over 4" stone): $15/sf*
- *Conventional concrete for comparison: $14/sf*

While the cost of porous asphalt is approximately twice that of standard asphalt, the use of porous asphalt often eliminates the need for large underground detention systems and the inlets and piping needed to convey runoff to the systems.

Note that the cost of porous concrete in a typical sidewalk installation is only slightly more than standard concrete, so porous concrete might be the preferred choice if the underlying soil infiltration characteristics are acceptable. The cost of the paver system, such as those used on Woodland Walk and Class of ’62 Walkway, are slightly higher than the porous and conventional concrete systems. A concern with large quantities of porous concrete is getting a uniform color for all batches used within one project.

The following factors may impact the life cycle cost of porous pavement:

- *The use of porous pavement may allow a site to meet the 20% reduction in existing impervious area and exempt the site from the Flood Control requirement, thereby reducing stormwater management costs for large subsurface detention facilities and the associated inlets and larger piping needed to convey runoff to the systems.*
- *The greater the material amount used, the lower the material and installation costs will be.*
- *Some research has shown that porous pavement requires less deicers to melt snow and ice.*
- *Porous pavement qualifies for a reduction in PWD stormwater fees.*
- *Higher maintenance costs to clean porous pavement may increase its lifecycle cost.*

Bioretention Areas / Rain Gardens

Bioretention areas and rain gardens provide the double function of stormwater management while enhancing the aesthetic quality of a landscape. The costs for bioretention areas can fluctuate widely. A relatively inexpensive system may be designed as an infiltrating area with several feet of amended planting soil. If infiltration is not possible, an underdrain system may be required. A bioretention area can also be located above a subsurface infiltration/detention system to provide additional stormwater runoff storage for larger rain events. Overflow/outlet structures are typically included in the design to allow runoff from large storms to bypass the system. The quantity and quality of the plantings will also affect the construction cost.

- *Bioretention area: $10-40/sf*

These factors may reduce the effective cost of a bioretention area:

- *While there may be increased long-term maintenance requirements in terms of weeding and trimming, these costs are offset by reduced mowing requirements and, once established, reduced irrigation, fertilizer, herbicide, and pesticide requirements.*
- *A bioretention area that manages runoff from impervious area qualifies for a reduction in PWD stormwater fees for the managed impervious area.*
- *While not providing a direct cost savings to the University, bioretention areas provide the intangible benefits of attractive and educational landscaping and improved wildlife habitat over conventional turf or ground covers.*

Subsurface Stormwater Management Facilities

It is difficult to provide a typical cost for subsurface infiltration/detention facilities. The systems may be constructed from a wide variety of materials (pipes of varying materials in a stone bed, concrete vaults, manufactured plastic storage units). The horizontal and vertical dimensions of the systems will vary widely depending on regulatory compliance requirements and site constraints limiting the extent of the systems. While the construction cost of a subsurface system will likely be greater than that of a comparable surface basin, the subsurface system preserves limited campus space for other uses; for example, a system located beneath a parking area allows for both vehicle storage and stormwater management on the same piece of ground.

By managing impervious area runoff in accordance with PWD's regulations, subsurface systems can reduce the PWD stormwater fees for the project site's parcel.

Capture and Reuse Systems

Like subsurface systems, it is difficult to quantify the cost of a system that captures and reuses rainwater for use inside a building because the system design will vary widely depending on the intended use of the captured water and the complexity of the water treatment and plumbing system within the building.

Capture/reuse, or rainwater harvesting, requires a significant investment in building infrastructure that is not needed if public potable water is used for all building uses. Depending on the intended use of the rainwater, a water treatment system may be required. A cistern, typically located in the basement of the building or outside of the building footprint, is required. A second parallel plumbing system is required to provide public water to the plumbing fixtures during dry periods when the cistern is empty.

From a sustainability education perspective, these systems send a strong message about natural resource conservation, but the relatively inexpensive cost of potable water typically results in a lengthy period for adequate return on investment for the construction costs.

If the captured rainwater is used year-round within a building in accordance with PWD's requirements (ie, system is capable of capturing one inch of runoff from the building roof and is used within 72 hours following the rain event), then the contributing roof area is considered managed and is eligible for a PWD stormwater fee reduction.

A capture/reuse system used to provide water just for landscape irrigation will save costs for potable water but, as discussed in Section 4, will not qualify for a PWD fee reduction.

PWD Stormwater Fees and Credits

In 2009, PWD began a five-year phase-in of a parcel-based stormwater fee system for all non-residential properties in the City. The fees will be fully implemented on July 1, 2013. The monthly fee consists of two parts: a Gross Area (GA) charge and an Impervious Area (IA) charge.

The GA charge is based on the gross area of the parcel and assumes that all lots are 70 percent impervious area. The fee is $0.53 per 500 square feet of gross parcel area. If a parcel has less than 70 percent impervious area, the property owner can apply to PWD for a credit that will reduce the fee to reflect the actual impervious area. The entire GA fee can be eliminated if a property's impervious area is less than 30 percent.

The IA charge is based on the impervious area located on a parcel. The fee is $4.17 per 500 square feet of impervious area. The fee can be reduced to the extent that the impervious areas are managed in accordance with PWD's regulations.

Projects with stormwater management practices constructed both before and since PWD instituted the stormwater regulations in 2006 must apply to PWD to receive credit for the facilities. The applications require the signature and seal of a licensed professional (engineer, architect, or landscape architect) and have an application fee of $150.00. The credits must be renewed every four years for a $50.00 fee.

Return on Investment Period for Stormwater Management Construction Costs

A reduction of the PWD stormwater fee provides an incentive to retrofit an existing parcel or building with a stormwater management practice that meets the PWD regulations. However, at this time, the fee structure may result in a lengthy return-on-investment period.

As an example, assume that a building with a 10,000 square foot roof is considered for retrofitting with a green roof and that the existing structure does not need any additional reinforcing to support the green roof (for reference, the green roof area on the Nanotechnology building is 8,300 square feet). At a typical cost of $12 per square foot for an extensive green roof (3-inch growing medium meeting PWD's minimum requirements), the approximate retrofit construction cost would be $120,000. The addition of the green roof would exempt the building from the Impervious Area charge. At the IA charge rate of $4.17 per 500 square feet per month, the monthly IA charge for 10,000 square feet of impervious area is $83.40, or an annual charge of $1,000.80. Therefore, the return-on-investment period for the green roof installation cost would be approximately 120 years, which certainly exceeds the life cycle of the roof and possibly the building.

Depending on the overall percentage of impervious area on the parcel, the addition of the green roof may also reduce the Gross Area charge (ie, by reducing the total impervious area below the assumed 70 percent impervious area), but because the GA charge is only $0.53 per 500 square feet of area, the cost impact will be less than for the IA charge ($4.17 per 500 square feet).

Still, the green roof retrofit will likely have a shorter return-on-investment period if the existing roof is in need of repair or replacement. The true cost of the green roof in this situation is its total cost less what would have been spent for a conventional roof replacement. As discussed previously, there will be other cost savings associated with the heating/cooling savings from the green roof installation and the reduction in the PWD fee.

Cost Sharing for Shared Stormwater Management Facilities

The block-by-block analysis depicts numerous locations that have potential for a porous pavement parking area, a subsurface stormwater management system, or a bioretention area that could be shared by two or more buildings which may be owned by more than one University department.

The design and construction costs for these shared systems could be equitably shared between the buildings' owners. Since the economic benefit obtained from a shared system would be the reduction in the PWD stormwater fees for the buildings sharing the system, the most equitable distribution of the design and construction costs would be based on the relative reductions in the PWD fees for the different owners. Since the fees are based on impervious area, the distribution of costs could be made based on each owner's percentage of the total impervious area being managed by the facility.

The situation is more complex when a new project constructs a stormwater management system which is overdesigned to accommodate runoff from existing unmanaged impervious area owned by a different entity. In this case, the owner of the new project will have likely incurred the bulk of the stormwater design and construction costs in the course of complying with the PWD regulations. For the owner of an existing building tying into the new system, the design and construction costs associated with his impervious area draining to the stormwater system may be more or less than his actual impervious area percentage of the total contributing area. The owner of the existing building, who is under no obligation to meet PWD's regulations, must weigh the construction and maintenance cost contribution towards the system against the savings that will be realized from the PWD stormwater fee reduction for his building.

Another complex scenario would occur if two new projects were slated for the same vicinity, but their construction schedules were offset by several years. If a shared system could service both projects, an agreement must be reached on how the two users will share the design and construction costs for the system. The second user could share in the costs at the time of design and construction, or could reimburse the first user at the time that he ties into the system. Difficulties could arise if the second user's plans and needs change in the years immediately following the construction of the shared system. It may be possible to expand a subsurface system at a later date to accommodate the second project, but this will require demolition of the overlying paved and/or landscaped areas and possible modifications to the system's outlet structure.

The agreements required between multiple owners for the design and construction of a shared system appear to be most straightforward for a retrofit project servicing existing properties. Scenarios involving one or more new projects will require careful planning and economic analysis to reach agreement on an equitable distribution of costs.

OPERATIONS AND MAINTENANCE CONSIDERATIONS

Under the PWD stormwater regulations, property owners must sign Operations and Maintenance (O&M) Agreements stipulating that the owner is responsible for the proper functioning and performance monitoring of the approved stormwater management practices. These agreements are legally binding for the life of the practices and are transferred to subsequent owners if the property is sold. The agreements give PWD the right to inspect all approved facilities on short notice and, if found to be in need of maintenance, PWD may perform the maintenance at the owner's expense. If the facilities are allowed to deteriorate to the point that they no longer provide their approved design function, the owner could be forced to completely reconstruct the facilities to return the site's stormwater management to compliance with PWD's regulations.

Perhaps the most significant shift in thinking required in the development of green stormwater management is the acceptance that considerable funds must be allocated to the long-term maintenance and monitoring of green stormwater management practices. The primary function of these practices is to recharge groundwater via infiltration and to improve stormwater runoff quality by mimicking the natural processes of infiltration and filtering by vegetation. During these processes, fine sediments and pollutants are removed from the runoff and are accumulated in the stormwater facilities. For the systems to continue to function as designed, the accumulated sediments must be periodically removed and the system must be repaired as needed to ensure that filtration and infiltration continue to perform as intended.

Determining a budget for maintenance is best approached with an understanding that the costs of facility maintenance should be viewed as protecting the investment in the original construction of the stormwater practices as well as protecting the University from liability issues. Additionally, the University's goal of promoting sustainability on campus should support the commitment to diligent maintenance in order to reduce the University's impact on the environment, especially the water quality of the Schuylkill and Delaware Rivers.

The O&M Agreements stipulate which approved practices must be maintained, what maintenance and monitoring procedures should be followed, and at what frequency. The agreements include the details of the stormwater practices that were shown on the approved construction plans.

The separate Operations and Maintenance Manual (O&M Manual) covers nine of the ten projects constructed by the University since the PWD regulations were enacted in 2006. The projects are described in more detail in Section 3 of the master plan. The tenth project, Locust Walk, meets the PWD regulations by providing tree disconnection credits. There are no physical stormwater practices to maintain so there is no O&M Agreement for the project. The O&M Manual includes the O&M Agreements, plans, and details for each project, as well as spreadsheets intended to assist in the scheduling and documentation of the required periodic maintenance and monitoring.

This section discusses considerations that should be accounted for in an O&M program for the University. The University must evaluate whether to monitor PWD requirements with its internal facilities staff or by contracting the work to a company that specializes in stormwater system maintenance. This discussion is saved for the end of this section, following an explanation of the components of a successful O&M program, so that the facilities staff can understand the implications of managing this effort in-house and what steps they need to take to successfully implement an O&M program.

Several companies specializing in stormwater facility maintenance were contacted as part of this master plan. These discussions provided approximate costs for the annual maintenance of several of the University's projects. The University should compare these contracted costs to their existing or anticipated expenditures using University staff and equipment for the required maintenance.

The Goals of Operations and Maintenance

There are three main components to an O&M program that are required in the PWD O&M Agreements:

- *Inspections - determine what, if anything, needs to be done to restore the stormwater management practice to its intended operating condition.*
- *Maintenance - clean, repair, or replace system components as necessary to restore the practice.*
- *Monitoring - evaluate is the system is meeting the performance criteria of the approved design.*

As mentioned above, a primary goal of maintaining a stormwater management practice is the protection of the original investment in the facility. Maintenance extends the life cycle of the practice by helping to maintain the sediment and pollutant removal rates over the life of the facility.

Beyond the financial implications of maintenance, the owner should recognize the environmental and societal benefits they are providing by ensuring the continued proper functioning of the system. Green stormwater practices improve water quality and provide a level of flood control and therefore benefit the environment downstream of the facility. Property is protected from excessive flooding and pollution. Wildlife habitats, both terrestrial and aquatic, benefit from cleaner, cooler water. The pollutants and sediments captured by the green infrastructure are removed during the maintenance process and can be appropriately disposed. Maintenance of the facilities ensures that they remain functional and safe and, in the case of landscaped surface systems such bioretention areas and green roofs, aesthetically pleasing.

Changes to Non-Stormwater Maintenance Practices

The first step of a successful O&M program is to identify landscape management practices currently employed on campus and to determine if changes need to be made to reduce the transfer of sediments and pollutants to stormwater management facilities. Doing so will reduce the maintenance requirements for the stormwater systems and will increase the longevity of the facilities. Costs incurred for staff training to implement these changes will be offset by cost savings from reduced use of materials and more efficient use of personnel.

The following information on the University's current non-stormwater maintenance practices was obtained via discussions with University maintenance staff.

For deicing of paved surfaces, the University maintains the campus sidewalks, parking areas, and driveways, as well as the City's sidewalks inside the street rights-of-way. The University uses a product called Ice B'Gone Magic, a rock salt treated with magnesium chloride. This material is applied only after snow stops falling. The material is applied with mechanical spreaders and the application rate on the spreader is set by a maintenance supervisior. The Philadelphia Water Department (PWD) Stormwater Guidance Manual recommends the use of such magnesium-chloride treated salt.

For the steps located outside the entrances to University buildings, the University uses calcium chloride, which is applied by the housekeeping staff of the different buildings. This product is less environmentally desirable than magnesium chloride products but its use is driven by a storage issue; the calcium chloride product is available in a form that is easily stored within each building.

The use of these products is preferable to sands, cinders, and grits which can make their way into stormwater practices and can clog the soil pores that allow infiltration of the stormwater to take place.

For porous pavements, mechanical removal of snow is typically sufficient and should be the primary treatment. Research has shown that accumulated snow melts faster on porous pavements due to the air circulation within the pavement and its stone subbase, which also allows heat from the subsurface soils to rise through the pavement. Melted snow is then able to drain directly through the pavement instead of staying in contact with remaining ice and snow and frozen pavement. In general, the "black ice" phenomenon should not occur on porous pavements. If deicers are required on porous pavements, smaller quantities of organic deicers should be used.

For the maintenance of landscaped areas, the University currently gathers tree leaves shortly after autumn leaf fall and composts them. Leaf litter and sediments deposited on the ground surface are currently collected using vacuums or leaf blowers. Vacuums should be used exclusively in the vicinity of stormwater management facilities as the leaf blowers may direct debris into the facilities. The maintenance staff should be informed of the locations of stormwater management facilities and the University might consider the installation of discrete, permanent signage in landscaped areas adjacent to porous pavement to remind workers to be especially diligent about minimizing the washing or blowing of debris onto porous pavements or into stormwater facilities. Bold, temporary signage should be used for alerting personnel when new construction is occurring adjacent to porous pavements.

The University currently uses compost tea (derived from its leaf composting operations) as fertilizer for landscaped areas. The university is also composting food waste from its dining facilities. Use of chemicals for fertilizing and weed control is minimal. Weeding of landscaped areas is done by hand. Diseased plantings are spot treated with chemicals using guidance from the University landscape architect.

It appears the University is following excellent sustainable practices for maintaining the paved and landscaped areas of the campus. Two possible areas for improvement may be the use of a magnesium chloride product for deicing of building entrances instead of the calcium chloride product currently used, and additional training of maintenance staff to understand the importance of the stormwater management facilities and how to minimize impacts to them during routine landscape maintenance.

General Maintenance Tasks for Green Stormwater Management Practices

The maintenance required for Penn's stormwater facilities are detailed in the O&M Agreements in a separate document prepared as part of this master plan. The O&M Agreements also specify the required frequency of inspections and maintenance. This section provides a general overview of the maintenance tasks for each of the more common stormwater practices. Additional recommendations are included in PWD's Stormwater Guidance Manual.

The O&M Agreements require that detailed records of inspection and maintenance be maintained. With all stormwater systems, maintenance should begin at the upstream end and proceed downstream. In this way, debris that may be accidentally transferred downstream during the maintenance process should be captured in the next component of the system to be cleaned, rather than discharging to a just-cleaned facility.

Green Roofs

Long-term green roof maintenance may be best accomplished by the installer of the green roof or a firm specializing in green roof maintenance. It is recommended that the green roof installer be responsible for maintenance for the first one or two growing seasons to ensure that the plantings have fully established themselves and that the growing medium drainage system is properly functioning.

Typical maintenance tasks include:

- *Irrigation as needed during the establishment period.*
- *Maintaining sufficient plant cover.*
- *Clearing of roof drains for proper drainage.*
- *Inspection and repair of growing medium.*
- *Testing of growing medium to determine fertilizer requirements.*

Porous Pavement

Porous pavement may be used for driveways, parking areas, and pedestrian walkways and plazas. The primary requirement for porous pavement maintenance is a specialty vacuum truck that helps to remove accumulated debris from the surface pores of the pavement. Conventional street sweepers and leaf blowers should not be used on porous pavements as these will direct surface debris into the pavement pores.

Typical maintenance tasks include:

- *Vacuum the paving surface at least twice per year. Ideally, vacuuming should occur in late spring to remove debris accumulated over winter and late autumn following leaf fall.*
- *Vacuuming of permeable walkways consisting of impervious pavers separated by gravel-filled joints will result in removal of some of the aggregate and is unavoidable. Replacement of the gravel with clean stone will help to restore the infiltration function of the walkway.*

- *To protect the surfaces of porous pavements, snow plow blades should be raised approximately one inch above the pavement.*
- *Use organic deicers (as discussed above).*
- *Inspect pavement for potholes, settlement, or broken pavement and repair as necessary.*
- *Do not use pavement sealers.*

Bioretention Areas

The primary task for bioretention area maintenance is management of the plantings. Bioretention areas may include overflow drainage structures and may be placed over top of subsurface detention/infiltration systems to provide for flood control or increased infiltration. Bioretention areas may be managed as part of the overall landscaping maintenance program on campus but the staff should be educated on the functioning of the overall system so that their maintenance actions do not inadvertently degrade the performance of the facility. Because bioretention areas function as infiltration and/or detention systems, PWD requires that they be monitored periodically to ensure that their storage volumes drain within 72 hours following a rainfall event.

Typical maintenance tasks include:

- *Vegetated stormwater facilities may require irrigation and increased maintenance for the first one or two growing seasons.*
- *Inspect the surface for clogged mulch and soil media.*
- *Remulch/repair eroded areas.*
- *Minimize use of fertilizer, herbicides, and pesticides (as discussed above). Overuse of fertilizers may benefit weed species.*
- *Spot treat diseased trees and shrubs. Remove and replace dead vegetation.*
- *Prune woody matter.*
- *Remove invasive plant species.*
- *Clear debris from overflow drainage grates and structures.*

Subsurface Infiltration/Detention Systems

Subsurface stormwater management facilities may require specialty equipment to adequately access the underground portions of the system for cleaning. High-pressure water pumps and powerful hose vacuums may be required to flush and remove accumulated debris from the system. PWD requires that subsurface systems be monitored periodically to ensure that their storage volumes drain within 72 hours following a rainfall event.

Typical maintenance tasks may include:

- *Protecting or stabilizing disturbed areas draining to system.*
- *Cleaning the grates and boxes of inlets draining to the facility.*
- *Flushing of accumulated debris from the underground portion of the system.*
- *Removing debris from the outlet structure.*

Demands on University Staff and Equipment

Maintenance staff must be trained to effectively maintain green stormwater practices. Ideally, they are not only trained in "what to do" but are given a thorough understanding of "how the system works."

By doing so, the personnel will understand the objective of the specific maintenance tasks and how those tasks fit into the overall operation of the system. This helps to prevent an uninformed action from inadvertently degrading the performance of a system.

Inspections of stormwater practices can often be accomplished with initial rapid assessments, perhaps 5 to 10 minutes for a single facility. However, the inspector must be trained to know "what to look for" to accurately determine what maintenance steps, if any, are required.

Ideally, stormwater facilities should be inspected within 24 hours of a significant rainfall event as this will help to provide visual evidence of potential problems with a system. PWD requires that systems be monitored periodically to ensure that they are draining down within the required period of 72 hours. Ideally, these monitoring procedures should occur 72 hours following a rainfall event of approximately one inch, to match the typical design of systems managing the first inch of runoff. Such storms may only occur once or twice in the spring and fall, so maintenance personnel must be ready to put other responsibilities on hold to maximize the inspection and monitoring time following the large rain events. Depending on the design of a proposed subsurface facility and its means of access for maintenance, confined space entry may be required for adequate inspections. This requires that the University have a confined space entry plan, at least three confined space-trained personnel for a single crew, as well as the necessary equipment which includes (but is not limited to) safety harnesses, air monitoring equipment, and possibly breathing apparatus.

Porous pavement areas are used for vehicles and pedestrians and require vacuuming of the surfaces. This is accomplished by using a specialized vacuum truck. If the University does not own one, a new vacuum truck typically costs approximately $70,000. The vacuuming is most efficiently and safely completed at night or on weekends, holidays, or college break periods when vehicle and pedestrian traffic is lowest. This may incur overtime pay fees for personnel. The University must anticipate the closing of parking areas to vehicles to ensure the pavement is cleared for vacuuming.

Because a successful O&M plan requires that personnel have a thorough understanding of the operation and maintenance requirements of stormwater management systems, as well as costly equipment, the University may want to consider contracting the maintenance work to a firm that specializes in the maintenance of stormwater management facilities. As the University continues to build new projects, the demands of complying with PWD's O&M Agreements for inspections, maintenance, and monitoring will present an increasing workload on the maintenance staff. Penn Park poses an especially daunting challenge with its dozens of inlets and multiple stormwater management systems.

Sharing Maintenance Costs for Shared Stormwater Management Facilities

Section 6 of this Master Plan discussed possible scenarios for sharing the construction costs for a single stormwater system that is used by more than one department of the University. For the sharing of maintenance costs, the issues are similar but more straightforward. Maintenance costs can be divided among the different entities based on their percentage contribution of runoff volume to the system. An agreement on the maintenance cost responsibilities would best be determined simultaneously with the decisions on construction cost sharing.

Contracting the Maintenance to a Specialized Company

As an increasing number of municipalities adopt green infrastructure programs and mandatory inspection and maintenance requirements, a market niche has developed to service the needs of land owners that are facing the requirements but do not have the experienced personnel or equipment to carry out the necessary tasks.

Duffield Associates contacted three of these specialty companies. Plans and details provided by the University for the Weiss Pavilion, Nanotechnology, and Shoemaker Green projects were provided to the firms with a request to prepare an estimated annual maintenance budget for each project.

It should be noted that the companies prepared the estimates without the benefit of a site visit to view the stormwater systems in detail. The estimates below should be considered approximate and for illustrative purposes only. Also, some firms do not do all types of maintenance and/or have different pricing schemes, so the costs below do not exactly correlate from firm to firm. Duffield Associates recommends that the University invite these firms (or similar firms) to provide detailed proposals for annual maintenance of all of the nine projects requiring maintenance. Contact information for the companies contacted as part of this planning evaluation is provided at the end of this section. With more detailed proposals, Penn can further assess the feasibility and cost competitiveness of accomplishing the required maintenance with in-house staff and equipment.

To understand what these costs cover, brief project descriptions are provided here:

- *The Weiss Pavilion project includes approximately 11,600 square feet of porous asphalt and approximately 15,300 square feet of permeable pavers (impermeable pavers with gravel-filled joints). These two areas require vacuuming twice per year.*
- *The Nanotechnology project includes 8,300 square feet of extensive green roof that includes two bioretention areas with deeper soils, two subsurface systems totaling approximately 2,900 square feet, and five sumped inlets.*
- *The Shoemaker Green project includes a subsurface system of approximately 22,300 square feet and two bioretention areas of approximately 2,600 total square feet.*

1. *Stormwater Solutions LLC is based in Philadelphia, and has contracts in Philadelphia maintaining facilities per PWD O&M Agreements. Their cost estimate includes the service of preparing the required PWD fee credit renewal applications every four years (including payment of the application fee). They provided the following estimated annual inspection and maintenance costs:*

   WEISS PAVILION

Porous pavement vacuuming (biannually):	*$2,100*

   NANOTECHNOLOGY

Total annual cost:	*$5,700*

   SHOEMAKER GREEN

Total annual cost:	*$3,900*

2. *Stormwater Maintenance LLC has offices in Maryland and Virginia, but has contracts in Philadelphia maintaining facilities per PWD O&M Agreements. They provided the following estimated annual inspection and maintenance costs:*

WEISS PAVILION

Porous pavement vacuuming (biannually): *$5,200*

NANOTECHNOLOGY

Total annual cost: *$9,800*

SHOEMAKER GREEN

Total annual cost: *$4,400*

3. *Apex Companies is located in Malvern, PA and has contracts in Philadelphia maintaining facilities per PWD O&M Agreements. They provided the following estimated annual inspection and maintenance costs:*

WEISS PAVILION

Porous pavement vacuuming (biannually): *$1,800*

NANOTECHNOLOGY

Green roof with bioretention areas (biannual): *

Two subsurface systems and inlets (biannually): *$12,000*

* *Apex Companies recommends that the green roofs be maintained by the installer or a landscaping company specializing in green roof maintenance.*

SHOEMAKER GREEN

Subsurface system (biannually): *$9,000*

Two bioretention areas (quarterly): *

* *Apex Companies recommends that the bioretention areas be maintained by the University landscaping staff.*

The range of annual maintenance costs for each site from the first two companies providing all services:

WEISS PAVILION:	$1,800-5,200
NANOTECHNOLOGY:	$5,700-9,800
SHOEMAKER GREEN:	$3,900-4,400
TOTAL ANNUAL COST FOR THE THREE SITES:	**$11,700-19,400**

Duffield Associates also contacted a specialty pavement vacuuming company, C&L Sweeper Service Corporation located in Jackson, NJ. They provided the following cost for the Weiss Pavilion project only. The low end of the cost range represents non-union rates during the day; the high end represents union rates at night or on weekends.

WEISS PAVILION

Porous pavement vacuuming (biannually): $2,000-$5,000

Maintenance Contract with Specialty Company

If the University decides to contract the maintenance work to a specialty company, the maintenance contract should include the following information:

- *Identify the specific parties responsible for the maintenance,*
- *Identify landscape or other subcontractors that may perform maintenance,*
- *Require an annual inspection with University personnel in attendance,*
- *Reference the specific annual maintenance tasks that must be performed and the frequency with which they must be performed,*

- *Require the contractor to provide inspection, maintenance, and monitoring reports for each site visit,*
- *Require the contractor to provide photographic documentation of all facilities at the start of the contract, and before and after each maintenance operation.*

Contact information for Maintenance Companies

The companies providing the above cost estimates can be contacted to obtain detailed cost proposals for the maintenance of the nine PWD-approved projects.

Stormwater Maintenance LLC
Hunt Valley, MD
Theodore Scott
410-785-0875
www.stormwatermaintenance.com

Stormwater Solutions LLC
Philadelphia, PA
David Plante
215-869-2025
www.stormwatersolutions.biz

Apex Companies
Malvern, PA
David Miller
610-722-9050
www.apexcos.com

C & L Sweeper Service Corp.
Gabriel Vitale
Jackson, NJ
732-886-1940
www.sweeping.com

Additional firms specializing in stormwater management maintenance can be found at:
www.bmpclean.org.

LEGISLATION ISSUES AND FUNDING OPPORTUNITIES

This section reviews the regulatory framework for stormwater management compliance and discusses pending stormwater regulation changes which may impact future development on the Penn campus. Potential sources of funding for stormwater management improvements are also reviewed.

Legislation Issues

Current Legislation

The City of Philadelphia instituted the Philadelphia Water Department's (PWD) stormwater regulations on January 1, 2006. These regulations set stormwater management criteria for new land development and redevelopment projects that disturb more than 15,000 square feet of earth during their construction (for certain watersheds in the City, the management criteria are required if more than 5,000 square feet is disturbed, but the 15,000 square foot trigger applies to the Penn campus). The management criteria are generally described in Section 2 of this plan and more detailed information is available in PWD's Stormwater Management Guidance Manual, available at www.pwdplanreview.org/StormwaterManual.aspx.

In September 2009, PWD submitted its Combined Sewer Overflow (CSO) Long Term Control Plan Update (LTCPU) to the Pennsylvania Department of Environmental Protection (PADEP). Following PWD's negotiations with PADEP, the LTCPU was amended and then approved by PADEP in June 2011. Known as the Green City, Clean Waters Program, the amended plan has a 25-year implementation period during which the City aims to comply with the federal Environmental Protection Agency's National CSO Control Policy of 1994 and Clean Water Act of 1972.

Rather than attaining compliance solely through the construction of sewage treatment improvements, the Green City, Clean Waters plan takes an innovative approach to seeking to reduce flows to the existing treatment system through the construction of green stormwater infrastructure that will significantly decrease the stormwater contribution to the CSO problem. By the end of the 25-year period, PWD will have invested approximately $2.4 billion ($1.2 billion in 2009 dollars) in the largest green stormwater infrastructure program ever implemented in the United States. The entire LTCPU document is available online at www.phillywatersheds.org/ltcpu/.

The PWD stormwater regulations provide the stormwater management criteria for new private and public construction projects that will help the City meet the commitment made to the Commonwealth of Pennsylvania in the LTCPU agreement.

As noted above, the basis of the LTCPU is the federal Clean Water Act of 1972. The Act was updated in 1990 and established the National Pollutant Discharge Elimination System (NPDES). Phase I of the NPDES program required stormwater management permitting for construction sites over 5 acres in area. Phase II of the NPDES program was signed into law in 1999 and reduced the permitting threshold requirement to land development projects disturbing 1 acre or more. NPDES Phase II permits are still required for current projects.

The Clean Water Act also requires each State to develop a list of impaired streams and rivers that do not meet the State's water quality standards. The State must set Total Maximum Daily Loads (TMDLs) for various pollutants, representing the maximum amount of a given pollutant that a stream or river can receive and still meet the State's water quality standards. Because the vast majority of stormwater runoff from the University's campus is directed to sewage treatment plants via the City's combined sewer system, the University is not directly responsible for meeting the TMDL levels for the Schuylkill River. However, as the steward of its campus environment, the University can reduce the burden on the City's sewage treatment infrastructure through implementation of green stormwater practices and judicious use of fertilizers, herbicides, pesticides, and deicing agents, as discussed in this Master Plan. This also applies to Penn Park, where a portion of the facility drains directly to the Schuylkill River.

At the state level, the Pennsylvania Stormwater Management Act of 1978 (commonly known as Act 167), requires counties to create watershed-level stormwater management plans. The Act also requires individual municipalities within each Pennsylvania county to adopt ordinances to implement the plans. In Philadelphia, Act 167 plans have been completed for the Darby-Cobbs Creek Watershed (2004) and the Tookany/Tacony-Frankford Watershed (2008), but not for the portion of the Schuylkill River located in Philadelphia. In 2008, the City signed an agreement with PADEP, committing to the development of a city-wide Act 167 planning process. According to Section 1.2.4.2 of the LTCPU document, the city-wide plan will be largely based on PWD's Stormwater Regulations. To date, Act 167 plans have been initiated for the Pennypack Creek Watershed (2008), the Poquessing Creek Watershed (2009), and the Wissahickon Creek Watershed (2010), but the LTCPU document does not provide a date of completion for the entire city.

Future Changes to Legislation and Impacts to Development

There are several potential changes to the existing legislation that could impact future development on the University's campus.

As mentioned above, new land development and redevelopment projects on the campus must comply with the PWD stormwater regulations if they disturb more than 15,000 square feet of earth. According to Section 1.2.4.2 of the LTCPU document, "PWD is considering modifications to the current regulations, including to lower the threshold of disturbance that triggers the regulations for compliance with the regulations from the current level of 15,000 square feet to a level of disturbance of 5,000 square feet." For reference, a typical parking area containing approximately 18 parking spaces with a central two-way drive aisle occupies approximately 5,000 square feet.

The lowering of the earth disturbance threshold to 5,000 square feet would have broader implications for future campus development. With this lower threshold, smaller building additions, parking lot expansions, or pedestrian area restorations could trigger the requirement to comply with the stormwater regulations and add project costs. Presumably, these smaller projects will be required to complete infiltration testing, provide stormwater management practices, and be submitted for approval through PWD's Technical Review process. The testing, design, permitting, and construction costs will likely significantly increase for development of the campus. The LTCPU document does not indicate when this lowered threshold might go into effect.

These smaller projects may lend themselves to the "banking" and "trading" approaches discussed in Section 6 of the Master Plan. For example, a large *Penn Connects* construction project could have the volume of its stormwater management system increased to capture roof runoff from an existing adjacent building. Under a trading approach, that additional management of existing impervious area could be used to offset the construction of a new parking area across the street from or in the vicinity of the large project. The offsetting of impervious area would allow the small parking area to be constructed without complying with the regulations. The construction of a larger subsurface infiltration/detention system for the new and existing buildings in this example would likely be less expensive than the construction of two separate systems, one for the new building and one for the new parking lot across the street. As noted in Section 6, this approach does not advance the University's overall goal of increasing its management of stormwater runoff above existing levels, but there would be no net increase in runoff.

The University's original Request for Proposal (RFP) for this Master Plan included a request for an assessment of the implications of managing 1.5 inches of runoff instead of the required 1 inch. The RFP indicated that this assessment be based on "future recommendations from the Department of Environmental Protection." Duffield Associates is aware (through its involvement in the ongoing rewriting of the Pennsylvania Stormwater Best Management Practices Manual) that this possible change is under consideration. Based on discussions with PADEP, the adoption of this new standard does not appear to be imminent. The LTCPU agreement between PADEP and PWD does not appear to give consideration to the regulations being revised to require this increased capture of runoff.

If PWD were to make the 1.5-inch requirement a part of the regulations, this would significantly increase construction costs for stormwater practices as they would be required to capture and manage 50 percent more runoff. If the University is considering the oversizing of a proposed stormwater management practice as part of a new development, Duffield Associates recommends that the University focus on providing management of 1 inch of runoff from existing unmanaged impervious surfaces near the project before considering management of 1.5 inches of runoff from the proposed impervious areas. This approach will maximize the water quality improvements to the "first flush" of runoff, the initial runoff volume at the start of a rain event that contains the highest concentration of pollutants (as described in Section 2 of the Master Plan).

At the state level, it was mentioned above that PWD has committed to PADEP to create a city-wide Act 167 plan. As noted in the LTCPU document, the city-wide plan would be largely based on PWD's Stormwater Regulations. Therefore, it is not anticipated that the Act 167 plan, once completed, will create new stormwater management requirements for development projects on the University's campus.

As part of a recent revision to Pennsylvania's Chapter 102 regulations, PADEP released an updated Erosion and Sedimentation Pollution Control Program Manual in March 2012 that details the design of erosion control devices for construction projects. The manual allows for the use of more updated technologies but does not place significant increased burden on site construction.

At the federal level, the Environmental Protection Agency has been working for several years on a "National Rulemaking" initiative designed to provide more uniform stormwater regulations across the country. The proposed changes have met significant opposition from the development community. The EPA has acknowledged that developing the cost-benefit analysis associated with addressing stormwater management on a nation-wide basis, taking into account the varying climates, soils, and land development patterns, has been challenging.

According to EPA's website, "EPA intends to propose a rule to strengthen the national stormwater management program by June 10, 2013 and complete a final action by December 10, 2014." Until EPA provides concise information on what regulatory changes may be coming to Pennsylvania, it is not possible to determine what impacts the changes may have on future campus development.

Funding Opportunities

This section reviews current opportunities for funding to support the construction of green stormwater management practices. Opportunities are reviewed at the local, state, and federal levels.

The Philadelphia Water Department (PWD) and the Philadelphia Industrial Development Corporation (PIDC) created the Stormwater Management Incentive Program (SMIP) Grant to offer assistance to non-residential PWD customers. PIDC is managing the program. PWD is funding the program and has the final decision on which applicants receive funding. Funding provided by the program provides incentive for property owners to implement green stormwater management practices that will reduce their monthly PWD stormwater fees.

The first round of grant applications ended on March 31, 2012. However, based on discussions with PIDC and PWD, Duffield Associates understands that the agencies intend to continue the program for several years, depending on its success and the availability of funding. To be competitive in the grant award process, the agencies recommend that the grant request range from $100,000 to $1,000,000. This suggests that PWD and PIDC are seeking to support projects of considerable size that will provide significant stormwater management benefits.

The grant funding may be applied towards the design and/or the construction of the proposed stormwater practices, but the funding must be applied to practices that provide stormwater runoff reduction, not general site improvements. The grant funding may be applied to new construction projects but only towards stormwater management that exceeds the regulation requirements for the proposed construction. For example, a subsurface infiltration/detention system for a new project could be enlarged to manage runoff from adjacent unmanaged buildings or ground-level impervious areas. The funding could be used for the design and construction of the expanded portion of the system.

The application process consists of submittal of a Concept Plan that provides information on the proposed stormwater management practices. The grant awardees may receive a SMIP grant, a SMIP grant supplemented by a low interest (1%) SMIP loan, or a low interest (1%) SMIP loan.

Full details of the application process and the Project Evaluation Criteria may be viewed at: www.phillywatersheds.org/what_were_doing.

In addition to the SMIP Grant program, PWD and PIDC provide an ongoing SMIP Loan program. Loans ranging from $75,000 to $1,000,000 at a 1% fixed rate are available. The term of the loans is consistent with the payback period of the stormwater management practices, up to 15 years. Applicants are expected to make at least a 10% equity contribution. Applications are submitted to PIDC and are reviewed on a quarterly basis (September 30, December 30, March 30, and June 30). A legal fee of approximately $1,500-2,500 is payable upon settlement.

At the state level, PADEP's Growing Greener II grant program has provided funding for stormwater-related projects since 2005. In 2011, the Pennsylvania Environmental Council received a $200,000 grant for a stormwater infiltration project in Philadelphia. From the list of 2011 grant awardees, it appears that the Growing Greener program is putting most of its funding towards stream restoration and mining reclamation projects. Information on the Growing Greener program can be viewed at: www.depweb.state.pa.us/portal/server.pt/community/growing_greener/13958.

Another state entity, PENNVEST, the Pennsylvania Infrastructure Investment Authority, offers grants through its Green Initiatives program and low-interest loans through its Clean Water State Revolving Fund (CWSRF). The grants and loans are available to private and non-profit organizations. Supported projects include green roofs, rain gardens, stormwater basins, and the planting of new trees along corridors to reduce runoff from the adjacent impervious areas. Information on the PENNVEST funding may be obtained at:
www.Portal.state.pa.us/portal/server.pt/community/about_us/9320.

RECOMMENDATIONS

This Stormwater Master Plan is intended to serve as a planning tool to find opportunities for increasing sustainability during new campus development or redevelopment projects. Stormwater planning should be incorporated early into the planning process for all new projects. This approach mirrors that of the Philadelphia Water Department (PWD), which requires that conceptual stormwater plans be reviewed and approved by the City prior to being eligible for approval by the City's Zoning Unit.

This section provides recommendations for integrating stormwater planning into the land use planning process, as well as for advancing the University's goal to increase the management of stormwater runoff from currently unmanaged existing sites. These recommendations are presented below as short-term (0 to 6 months), mid-term (6 months to 5 years), and long-term (beyond 5 years). Some tasks may be accomplished within the specified timeframe, but many are intended to be adopted indefinitely into the future.

Primary Stormwater Planning Recommendations

Before discussing the short-, mid-, and long-term recommendations, several recommendations are provided that should be considered as a basis for all stormwater planning on campus.

1. *Pursue increased stormwater management on a block-by-block approach rather than a campus-wide approach, as discussed in Sections 2 and 5 of the Master Plan. The block-by-block approach is in keeping with a primary tenet of sustainable stormwater management: to manage rainfall where it falls. The block-by-block diagrams in Section 5 depict potential retrofit opportunities to provide stormwater management for currently unmanaged impervious areas.*
2. *All new land development and redevelopment projects should strive to provide a 20 percent reduction in impervious area as compared to pre-development conditions. By doing so, a new project must only comply with the Water Quality requirement of the PWD stormwater regulations. Such a project is thereby exempt from the Flood Control Requirement, which typically requires large costly subsurface facilities and associated piping and inlets. Beyond the cost considerations, the reduction of impervious area contributes to the primary goal of PWD's Green City, Clean Waters program: the reduction of the volume and frequency of Combined Sewer Overflows (CSOs).*
3. *The primary stormwater management goal of all construction projects should be the management of the first one inch of runoff from impervious surfaces for new and retrofit projects, ideally via infiltration if soil conditions permit. The University's original Request for Proposal for this Master Plan requested an additional assessment of the implications of managing the first 1.5 inches of runoff. If the University is considering the oversizing of a proposed stormwater management practice as part of a new development, it is recommended that the University focus on providing management of 1 inch of runoff from existing unmanaged impervious surfaces near the project before considering management of 1.5 inches of runoff from the proposed impervious areas. This approach will maximize the water quality improvements to the "first flush" of runoff from the largest area of impervious*

surface. The first flush is the initial runoff volume at the start of a rain event that contains the highest concentration of pollutants (as described in Section 2).

4. *The large projects envisioned in the Penn Connects and Penn Connects 2.0 plans may provide the most significant opportunities for attaining meaningful stormwater management practices. These projects also provide the opportunity for consideration of new stormwater management technologies, such as those described in Section 4 of the Master Plan. Considerable focus should be placed on conceptualizing innovative stormwater management opportunities during the early planning phases of these projects, including an evaluation of the potential for trading, shared systems and grant funding.*
5. *The University may want to consider increasing the storage capacity of stormwater management facilities on new projects to accommodate the future rainleader connection of adjacent existing buildings and runoff from impervious areas which are currently unmanaged. This goal may be limited by the configuration of existing roof downspouts and existing impervious area drainage inlets and piping in the vicinity of the proposed new projects. However, identifying these opportunities will be most successful if considered early in the planning process.*
6. *The University should consider stormwater management retrofits of existing buildings and impervious as part of the University's facility renewal and reinvestment program. When a building roof is scheduled for repair or replacement, consider the addition of a green roof if the existing structure will support it. When paved areas are scheduled for repaving or repair, assess the feasibility of replacing the existing impervious pavement with porous pavement, and/or consider the potential for adding subsurface or surface stormwater management facilities to manage the runoff from these pavements.*
7. *The University may want to consider investing in green roofs as a signature feature on Penn's campus. The many stormwater benefits of green roofs have been discussed in the previous sections of the master plan. While retrofitted green roofs often provide a lengthy rate-of-return on the construction costs, green roofs on new buildings may provide cost savings by reducing ground-level stormwater management facilities (which also saves land for other uses), increasing lifecycles of roof membranes, and reducing heating and cooling costs.*

   As solar power technology continues to advance, competition for roof space may develop between energy production in the form of solar panels and stormwater management in the form of green roofs. Depending on the proposed building roof configuration, one practice may be more practical than the other, but a roof accommodating both technologies is an option. In certain configurations, PWD may give stormwater management credit and fee credit for impervious solar panels that drain to the green roof portion of a roof.
8. *The University should assess the feasibility and maintenance cost of installing porous pavements for all new impervious areas as a way to reduce the need for subsurface infiltration/detention systems. Even though PWD does not require infiltration testing for porous pavement installations, Duffield Associates recommends testing for infiltration practices to reduce the potential for system failure.*
9. *One of the simplest ways to reduce stormwater management requirements is to reduce*

impervious area. As part of its sustainability goals, the University should continue the current policy to remove surface parking areas by more effective use of perimeter parking structures. The Penn Connects plan envisions improvements to the campus's bicycle and public transportation infrastructure. Greater reliance on these more sustainable transportation modes could ultimately lead to reduced impervious area on campus.

10. *A diligent Operations and Maintenance Program should be established to protect the investment in the stormwater management practices already constructed and planned. As with any engineered system, periodic preventive maintenance will always be more cost-effective than delaying maintenance until the system exhibits signs of impending failure. In the case of an infiltrating stormwater practice, system failure would likely require complete excavation and reconstruction of the facility in order for it to maintain compliance with PWD stormwater regulations.*
11. *The University should specify the use of double-ring infiltrometers for all infiltration testing. This is the methodology preferred by PWD and PADEP, and should provide the most reliable information for infiltration system design. Based on the testing results from the new projects constructed since 2006, the infiltration capacity of the campus's soils are highly variable and can only be accurately assessed through infiltration testing at the specific location and depth of a proposed infiltration system.*

Short-term Recommendations (0 to 6 Months)

The following recommendations should be given top priority, either because they are critical to the success of the University's goal of increasing stormwater management, have immediate cost saving implications, or, in the case of the first item, have an impending deadline for action.

1. *The University should and obtain cost proposals for stormwater facility maintenance from several companies specializing in these operations, as discussed in Section 7. Stormwater facility maintenance requires specialized knowledge and equipment. Using a private company may be cost effective by reducing the training and equipment costs required to implement an internally managed successful O&M program. At least one of the maintenance companies referred to in Section 7 also manages the application process for the mandatory 4-year renewals of PWD stormwater fee credits.*
2. *The University should verify that all applications have been submitted to and approved by PWD for obtaining the stormwater fee credits for the projects constructed since 2006. If applications have not been made, submit the necessary documentation to PWD to receive the appropriate fee credit. The application process, while requiring an engineer's seal, is a fairly straightforward process and the initial verification could perhaps be performed by a University intern.*
3. *The University should review the PWD billing information for all University properties. Duffield Associates has found errors in the PWD data for other clients. If errors are discovered, submit the necessary documentation to PWD to correct the discrepancies and lower the PWD fees for the parcels in question. Ownership verification and ground-truthing of the existing impervious areas shown for each parcel on PWD's billing website could perhaps be performed by a University intern.*
4. *The University should continue to meet regularly with PWD to discuss ongoing stormwater*

planning issues on campus. Additional topics of discussion might include banking and trading of impervious areas (as described in Section 5), potential funding opportunities, and pending legislation changes that might impact future development on campus.

Mid-term Recommendations (6 Months to 5 Years)

The following recommendations should be given secondary priority. They could be initiated before the six month timeframe, but these items do not have immediate significant cost implications to the University.

1. *The block-by-block diagrams in Section 5 of the Master Plan indicate which existing buildings may be potential candidates for green roof retrofitting. The analysis of each of the existing buildings was limited to a determination of building ownership and the general configuration of the building's roof. The next step is for the University to develop a priority listing of potential green roof retrofit candidates so that these can be evaluated as funding becomes available, or as the existing roofs become due for roof replacement or repairs. More detailed information on assessing green roof retrofit feasibility is provided at the end of this section.*
2. *At the same time that existing buildings are being evaluated for their green roof retrofitting feasibility, the potential to disconnect existing roof downspouts from a direct connection to the City's combined sewer system and redirect them to new subsurface infiltration/detention facilities should also be assessed. As a separate study, Duffield Associates reviewed the available plans for the University's buildings and mapped the water, storm and sanitary sewer lateral locations. The storm sewer laterals for many existing buildings are directed towards the combined sewers located in the adjacent City streets. In these situations, it may be difficult to redirect the laterals to new subsurface stormwater systems located in the block's interior, unless plumbing adjustments can be made within the basements of the buildings. Such an adjustment would require rerouting the roof drain lateral through a new location in the building's foundation, which may be difficult and costly.*
3. *As new projects are planned and designed over the next 5 years, the following green stormwater practices should be considered as part of the overall stormwater management strategy for each project: capture and reuse of stormwater rainfall, conversion of turf grass areas to bioretention areas and meadow areas, and planting of new trees.*

   As discussed in Section 6, capture/reuse systems can have significant construction costs, especially if water treatment is required for the intended use of the captured rainwater. However, operations such as vehicle and equipment washing may not need treated water. Captured rainwater may be used for landscaping, such as is occurring at Penn Park, but PWD does not give stormwater management credit or fee credit for irrigation uses of harvested rainwater.

   Conversion of existing lawn areas to more sustainable vegetated landscapes such as bioretention areas and meadow areas will reduce stormwater runoff. Once established, the native vegetation planted in these areas will typically require less frequent maintenance than the lawn areas they have replaced.
4. *The University may want to gather the construction cost data for the stormwater management practices built as part of the projects constructed since 2006. Typical construction costs for various stormwater systems are provided in Section 6. However, an*

analysis of construction costs for the University's projects may provide valuable cost-benefit information for other projects.

5. *As mentioned above, Duffield Associates completed a separate utility study that plotted existing water, storm and sanitary sewer lateral locations. In addition, the University has plotted the chilled water and steam lines across the campus. The University may want to consider obtaining utility plans via the PA One Call System for all utilities located in the City streets. PWD maintains excellent archived plan records for water, storm, and sanitary sewers. While most of this information is in the form of hand-drawn plans, it has been converted to digital format so would be easily digitized into the University's master utility cad files. This street utility information would allow assessment of the feasibility of cross-street transfers of stormwater (from one block to the next) as discussed in the stormwater planning procedural framework outlined in Section 5. This information would also be required for conceptual planning of potential green street construction.*

   To complete the mapping of utilities located in the interiors of the campus' city blocks, the University may want to review available plans and plot the remaining utilities such as gas, electric, and phone. This information would help identify potential conflicts with proposed subsurface stormwater management facilities, as well as general utility planning for new projects.

Long-term Recommendations (Beyond 5 Years)

The following recommendations should be considered once the short-term and mid-term recommendations are addressed. These recommendations may provide the lengthiest return-on-investment periods but can still advance the University's goals of increased sustainability. Several of the recommendations focus on integrating the goals of the Master Plan into the University's curricula and research efforts.

1. *The University may want to explore potential "green street" development on campus in conjunction with PWD and the City's Streets Department. Liability issues associated with directing potentially contaminated stormwater runoff from public streets onto the University's private property were briefly discussed in Section 5. If the University chooses to pursue the creation of green streets on campus, its legal department should assess the liability implications of this shared utility scenario. In addition to the sharing of design and construction costs, agreements will need to be reached regarding responsibilities for the long-term maintenance of shared facilities. The best candidates for green streets on campus will be those streets with the fewest existing utilities, lower levels of vehicle usage, and higher levels of pedestrian traffic. Ideally, the existing soils will allow for infiltration, but street rights-of-way often contain highly compacted soils.*
2. *The University may want to promote stormwater research in academic programs. This research could be conducted in conjunction with PWD, PADEP, or other local, state, or federal agencies.*
3. *The University might consider a program with more extensive monitoring and evaluation of system performance than that required by PWD. Perhaps in collaboration with appropriate academic programs, collected data could be used to evaluate critical design criteria for*

various stormwater practices. For example, the detailed collection and analysis of rainfall data and use of captured rainwater for irrigation water at Penn Park could improve the design of other potential capture/reuse systems on campus.

Green Roof Retrofit Analysis Guidelines

As mentioned under Mid-term Recommendation #1 above, the block-by-block diagrams in Section 5 of the Master Plan indicate which existing buildings may be potential candidates for green roof retrofitting. The block-by-block analysis did not evaluate the structural design of the buildings or consider the University's future plans for the buildings. The following guidelines are suggested for evaluating the structural capacity of existing buildings for green roof retrofitting feasibility.

1. *The University should prepare an initial list of potential green roof retrofit candidates using the block-by-block diagrams in Section 5 of the Master Plan. Buildings slated for impending demolition or with known structural deficiencies should be eliminated from the list.*
2. *Some general guidelines for initially identifying existing buildings as "good candidates" and "poor candidates" for green roof retrofits are provided here. This classification is based on the evolution of structural design for buildings over the last century. Older buildings tend to be overdesigned so that their structures are more likely to be able to support the additional loading of the components of a green roof. Good candidates are typically older (pre-1950's) single- or multiple-story reinforced concrete buildings. Institutional buildings constructed from the 1950's through the 1970's may also be good candidates. Modern one-story buildings are typically poor candidates for green roof retrofitting. Modern building roofs constructed with steel open-web joist roof framing are also poor candidates.*
3. *A typical 3-inch-thick extensive green roof in a saturated condition (i.e., following a rainfall event) will add approximately 10 to 15 pounds per square foot to the building's roof structure. As recommended above, the University might consider creating green roofs intended for public access. The use of a roof as public space typically adds 100 pounds per square foot to the required loading of the roof structure. For this reason, older existing buildings may be able to support a typical extensive green roof, but may not be able to support the load demands for use of the roof as public space. New buildings can be designed to meet the higher loading requirements for public access. Construction costs will be higher, though these are somewhat offset by the less tangible benefits of creating a unique public gathering space that increases usable green space on campus, and the preservation of ground-level space for other uses.*
4. *The most important factor contributing to a quick determination of green roof retrofit feasibility is the existence of the original structural drawings for the building or, if the building has been modified since construction, drawings that accurately depict the current conditions of the building's structure and roof. With these drawings, a structural engineer is able to quickly complete an initial green roof feasibility analysis for a building. The University might consider using an intern (with some structural engineering knowledge) to locate the original structural drawings for the green roof retrofit candidate buildings from Penn's Falcon drawing database. Once the relevant drawings are collected for the retrofit candidate buildings, the University could engage a structural engineer experienced in green roof retrofit analysis to complete the initial evaluations of the structural capabilities of the selected buildings to support a green roof.*

It is anticipated that the information presented in the Stormwater Master Plan will evolve over time as the University's plans for future development unfold, new stormwater management technologies and techniques are created, and with the adoption of new stormwater regulations at all levels of government. This Master Plan should be revisited in five years to respond to the University's development and to maximize the use of emerging state-of-the-art design methodologies for sustainable stormwater management.

APPENDIX A

Representative Stormwater Management Details

This appendix contains typical construction details for various green stormwater management practices. All provided details, except for the green roof detail, were approved by PWD for projects designed by Duffield Associates or LRSLA Studio.

A CD is included with the Master Plan containing AutoCAD 2012 and pdf files of the details.

These details are illustrative only, and are provided for general guidance. It is the responsibility of the engineer to determine the applicability of these details to stormwater designs for particular projects and sites, and modify them accordingly. Duffield Associates does not warrant the applicability of these details to other sites or approval by the Philadelphia Water Department on other projects and is not responsible for problems arising from the use of this information.

Green Roof

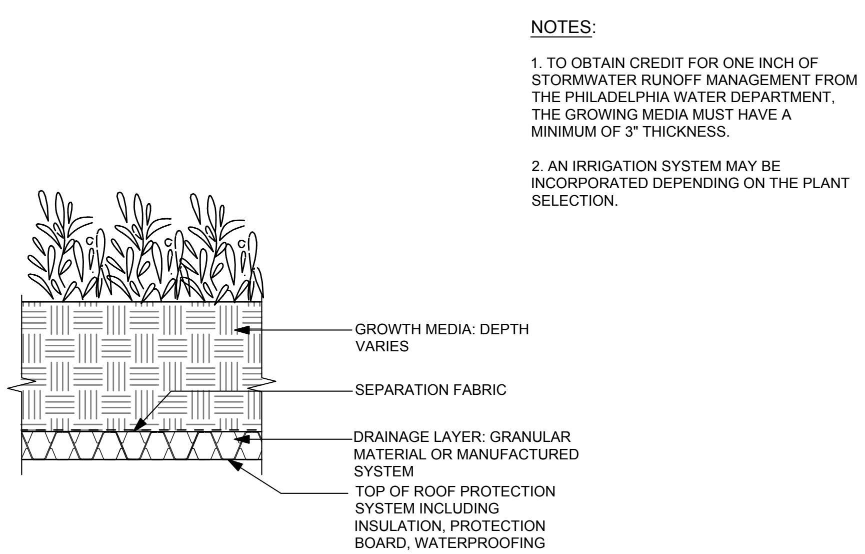
Green roofs are best designed by engineers or architects experienced in their design. Section 4 of the Master Plan includes information on a variety of manufactured green roof systems. Most manufacturers will provide design assistance and some will provide installation and maintenance services.

The attached detail depicts the typical components of a green roof and is not intended to represent an actual design.

It is critical that the roof's waterproof membrane be in excellent condition before installing the green roof components. Retrofitting a green roof to an existing building will be most cost-effective if installed when the roof membrane is scheduled for replacement.

A green roof with a growing medium of 3 inch minimum thickness meets the Water Quality Requirement of the Philadelphia Water Department's (PWD) Stormwater Regulations. It is considered to provide the necessary management for the first inch of runoff and is eligible for stormwater fee credits. The green roof can also contribute to the 20 percent reduction of existing impervious area that exempts the project from the Flood Control Requirements.

Additional information on green roofs can be found in the PWD's Stormwater Management Guidance Manual.



DETAIL: GREEN ROOF SECTION, TYP.

Scale: N.T.S.

Porous Pavement

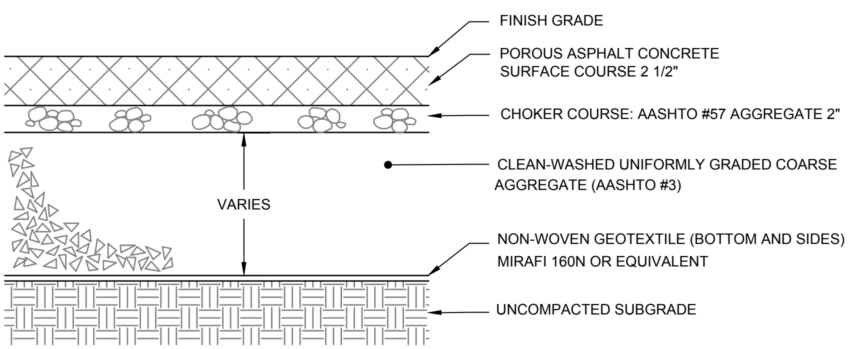
Porous pavements are designed with a porous asphalt or concrete surface over an open-graded stone subbase. This allows rainwater to pass through the pavement layer and drain through the stone subbase to the underlying soils for infiltration.

Porous pavement slopes should be less than 5 percent. The soil subgrade should be uncompacted and level. The pavement's stone subbase should include an overflow drain system that prevents accumulated water from saturating the porous asphalt or concrete pavement layer.

Porous pavement meets the Water Quality Requirement of the Philadelphia Water Department's (PWD) Stormwater Regulations if the only stormwater entering the system is the rainwater that falls on it. In this situation, it is considered to provide the necessary management for the first inch of runoff and is eligible for stormwater fee credits.

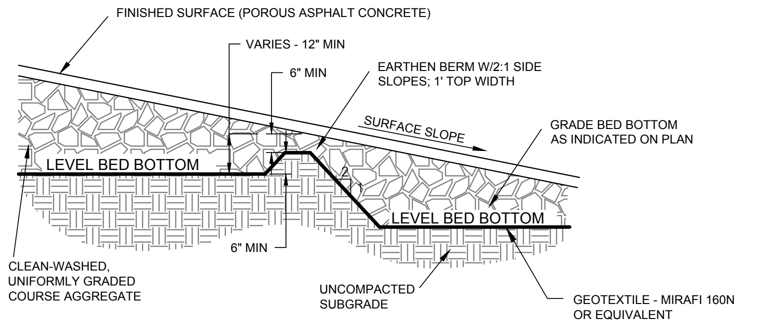
The stone subbase can also be used as a detention system by connecting nearby roof drains to the subbase, or adjacent impervious pavements (e.g., sidewalks) can sheet flow to the porous pavement area. In this condition, the porous pavement area cannot contribute to the 20 percent reduction of existing impervious area that exempts a project from the Flood Control Requirements, but the porous pavement area and roof/impervious pavement areas managed by the system would be eligible for stormwater fee credit.

Additional information on porous pavement can be found in PWD's Stormwater Management Guidance Manual.



NOTE:
NO RECYCLED CONTENT IN POROUS ASPHALT.

DETAIL: POROUS ASPHALT CONCRETE WITH INFILTRATION BED
Scale: N.T.S.



DETAIL: EARTHERN BERM BETWEEN INFILTRATION BEDS WITH VARYING BED BOTTOM ELEVATIONS

Scale: N.T.S.

ON-SITE SOILS FREE OF ORGANIC MATERIAL, DEBRIS AND ROCK FRAGMENTS IN EXCESS OF 3 INCHES IN THEIR LARGEST DIMENSION MAY BE SUITABLE AS STRUCTURAL FILL FOR CONSTRUCTION OF THE PROPOSED "EARTHEN BERMS" ONLY. IT IS POSSIBLE THAT THE FINE-GRAINED SOILS COULD BE UTILIZED AS "EARTHEN BERM" FILL; HOWEVER, THESE SOILS CAN BE PRESENT WITH AN IN-SITU MOISTURE CONTENT THAT EXCEEDS THE TYPICAL RANGE THAT WOULD ALLOW THE RECOMMENDED COMPACTION TO BE ACHIEVED. AS A RESULT, DRYING OF THESE SOILS MAY BE REQUIRED TO ACHIEVE THE RECOMMENDED COMPACTION. DRYING FINE-GRAINED SOILS REQUIRES AN AREA IN WHICH TO SPREAD THEM OUT, EXTENDED PERIODS OF WARM, DRY WEATHER, AND TIME. ADDITIONALLY, FINE-GRAINED SOILS ARE MORE SUSCEPTIBLE TO RUTTING AND DISTURBANCE FROM CONSTRUCTION TRAFFIC THAN COARSE GRAINED SOIL.

FILL FOR THE EARTHEN BERMS SHALL CONSIST OF PREDOMINATELY GRANULAR SOILS CONFORMING TO THE FOLLOWING REQUIREMENTS:

SIEVE	% PASSING
1 ½"	100
NO. 4	50 - 100
NO. 10	25 - 75
NO. 200	≤ 25

POROUS PAVEMENT NOTES:

1. BITUMINOUS SURFACE SHALL BE LAID WITH A BITUMINOUS MIX OF 5.75% TO 6% BY WEIGHT DRY AGGREGATE. IN ACCORDANCE WITH ASTM D6390, DRAIN DOWN OF THE BINDER SHALL BE NO GREATER THAN 0.3% AGGREGATE; GRAIN IN THE ASPHALT SHALL BE A MINIMUM 90% CRUSHED MATERIAL AND HAVE THE FOLLOWING GRADATION:

POROUS ASPHALT GRADATION		
US STD. SIEVE SIZE	PARTICLE SIZE (IN)	PASSING SIEVE (%)
1/2 INCH	*0.05"*	*100*
3/8 INCH	*0.375"*	*92-98*
NO. 4	*0.187"*	*34-40*
NO. 8	*0.0935"*	*14-20*
NO. 16	*0.0469"*	*7-13*
NO. 30	*0.0059"*	*0-4*
NO. 200	*0.0029"*	*0-2*

2. NEAT ASPHALT BINDER MODIFIED WITH AN ELASTOMERIC POLYMER TO PRODUCE A BINDER MEETING THE REQUIREMENTS OF PG 76-22 AS SPECIFIED IN AASHTO MP-1. THE ELASTOMER POLYMER SHALL BE STYRENE-BUTADIENE-STYRENE (SBS), OR APPROVED EQUAL. APPLIED AT A RATE OF 3% BY WEIGHT OF THE TOTAL BINDER.

3. HYDRATED LIME SHOULD BE ADDED AT A DOSAGE RATE OF 1% BY WEIGHT OF THE TOTAL DRY AGGREGATE TO MIXES CONTAINING GRANITE. HYDRATED LIME SHALL MEET THE REQUIREMENTS OF AASTM C 977. THE BINDER FROM THE AGGREGATE AND THE ACHIEVE A REQUIRED TENSILE STRENGTH RATE (TSR) OF AT LEAST 80% ON THE ASPHALT MIX WHEN TESTED IN ACCORDANCE WITH AASHTO T 283. THE ASPHALT MIX SHALL BE TESTED FOR IN RESISTANCE TO STRIPPING BY WATER IN ACCORDANCE WITH ASTM D-1664. IF THE ESTIMATED COATING AREA IS NOT ABOVE 95 PERCENT, ANTI-STRIPPING AGENTS SHALL BE ADDED TO THE ASPHALT.

4. THE ASPHALTIC MIX SHALL BE TESTED FOR ITS RESISTANCE TO STRIPPING BY WATER IN ACCORDANCE WITH ASTM D-3625. IF THE ESTIMATED COATING AREA IS NOT ABOUT 95 PERCENT, ANTI-STRIPPING AGENTS SHALL BE COATED TO THE ASPHALT.

5. ALL ADJACENT FABRIC SEAMS SHALL OVERLAP 16 INCHES. DURING CONSTRUCTION, THE GEOTEXTILE SHALL BE SECURED AT LEAST 4 FEET OUTSIDE OF THE STONE BED, THEN TRIMMED FOLLOWING THE PLACEMENT OF THE AGGREGATE AND CHOKER COURSE.

Permeable Pavers

There are two types of permeable paver systems. In one system, the pavers themselves are made of porous asphalt or concrete. In the other system, the pavers are made of impervious brick or concrete, and are installed with ¼-inch-wide joints separating the pavers that allows stormwater runoff to pass through the joints to the underlying stone subbase.

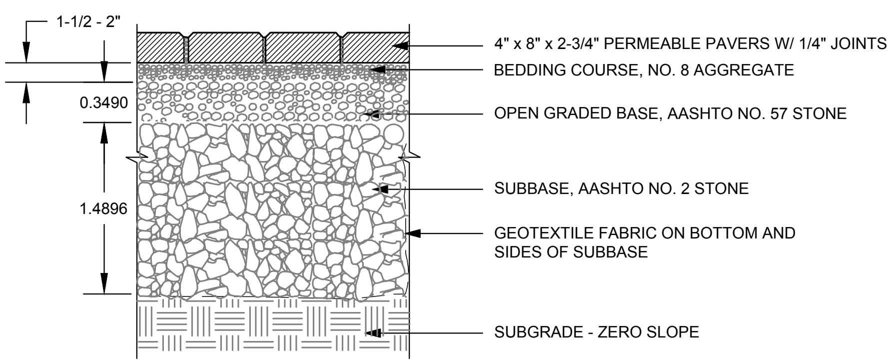
The University installed the latter type of system at Woodland Walk.

As with porous pavement, permeable paver systems are designed with an open-graded stone subbase. This allows rainwater to pass through the pavement layer and drain through the stone subbase to the underlying soils for infiltration.

The soil subgrade should be uncompacted and level. It is critical that the subbase stone be "clean washed" so that the aggregate contains no fine particles that could clog the underlying soil pores essential for infiltration.

As with porous pavement, permeable paver systems meet the Water Quality Requirement of the Philadelphia Water Department's (PWD) Stormwater Regulations if the only stormwater entering the system is the rainwater that falls on it. In this situation, it is considered to provide the necessary management for the first inch of runoff and is eligible for stormwater fee credits.

The stone subbase can also be used as a detention system by connecting nearby roof drains to the subbase. In this condition, the permeable paver area could not contribute to the 20 percent reduction of existing impervious area that exempts a project from the Flood Control Requirements, but the permeable paver area and roof/impervious areas managed by the system would be eligible for stormwater fee credit.



DETAIL: PERMEABLE PAVER SECTION, TYP.

Scale: N.T.S.

Bioretention / Subsurface Detention

The attached design represents a combination bioretention/subsurface detention system. All of the details refer to a single system.

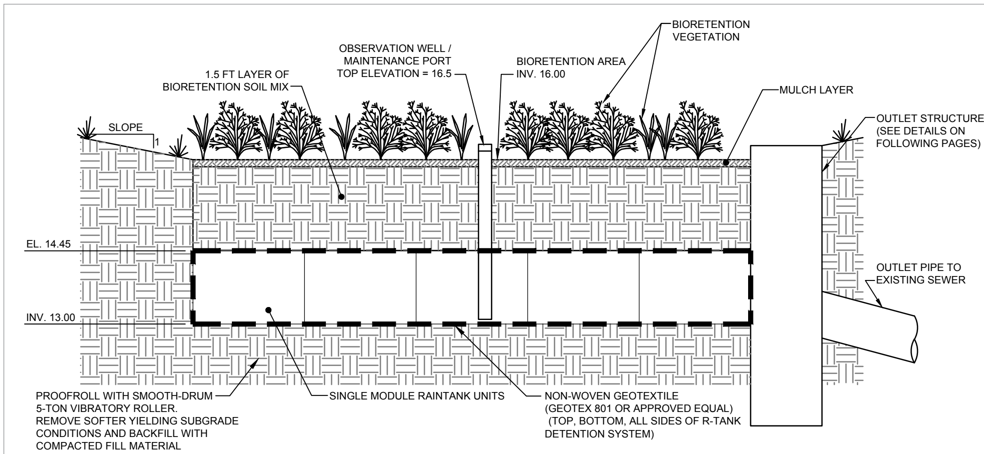
Stormwater runoff flows into the surface bioretention area and seeps into the planting soil mix. Water that is not taken up by the bioretention plantings drips into the subsurface detention system consisting of plastic ACF Raintank units. These units provide 95% water storage volume for the system volume. This compares to only 40% water storage volume for a detention bed constructed of stone aggregate.

This system could work in an infiltrating or non-infiltrating condition depending on the site soils.

The details also depict an outlet structure designed to manage the outflow from the system. The structure is connected to a combined sewer and so includes the required trap that prevents sewer gases from exiting the structure. A similar system is used at the Nanotechnology Building.

There is considerable discussion in the engineering community about whether geotextile should be placed at the bottom of infiltrating systems. Duffield Associates understand that PWD specifies this geotextile in their designs but they leave the decision to the design engineer on private projects.

Chapter 8 of PWD's Stormwater Management Guidance Manual includes listings of recommended plant species as well as invasive species that are not permitted.



FOR ADDITIONAL INFORMATION PLEASE CONTACT: ACF ENVIRONMENTAL, 1-800-448-3636, www.acfenvironmental.com

DETAIL: BIORETENTION AREA WITH RAINTANK DETENTION SYSTEM

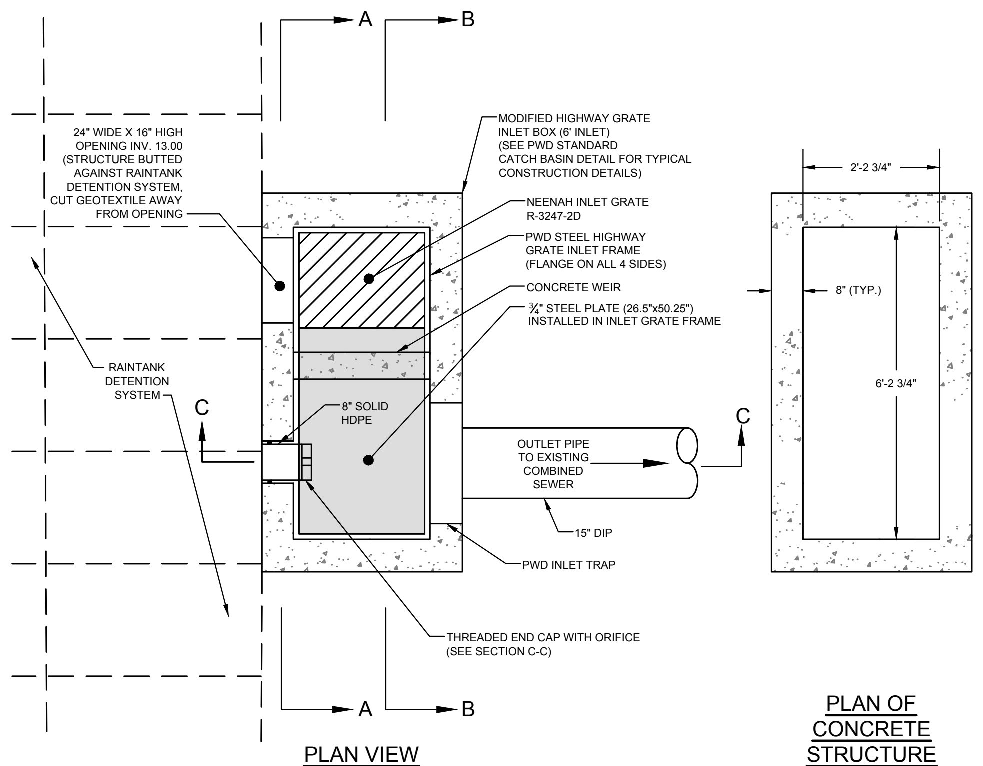
Scale: N.T.S.

SOIL MATERIAL SPECIFICATIONS FOR BIORETENTION AREA

MATERIAL	SPECIFICATION	SIZE	NOTES
PLANTINGS	(SEE PWD STORMWATER GUIDANCE MANUAL FOR ACCEPTABLE PLANT SPECIES)	N/A	
PLANTING SOIL** (36.0" DEEP)	SAND 33% MULCH 33% PEAT 33%	N/A	USDA SOIL TYPES LOAMY SAND, SANDY LOAM OR LOAM pH 6.5-7.5 SALTS <500ppm Mg 35 lb/ac CEC 8-25 cmd/kg Po 75 lb/ac K 85 lb/ac
MULCH (3"DEEP)	TRIPLE-SHREDDED HARDWOOD (AGED 6 MONTHS)	N/A	
GEOTEXTILE	GEOTEX 801 OR EQUIVALENT	N/A	MINIMUM PERMEABILITY OF 110 GPM/SF

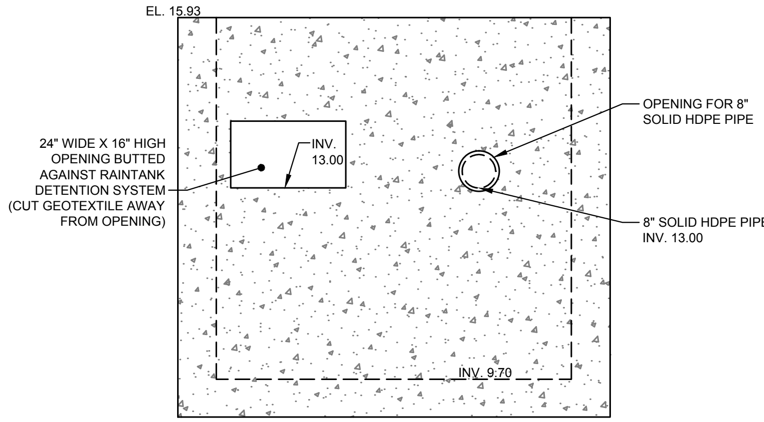
DETAIL: BIORETENTION AREA WITH RAINTANK DETENTION SYSTEM

Scale: N.T.S.

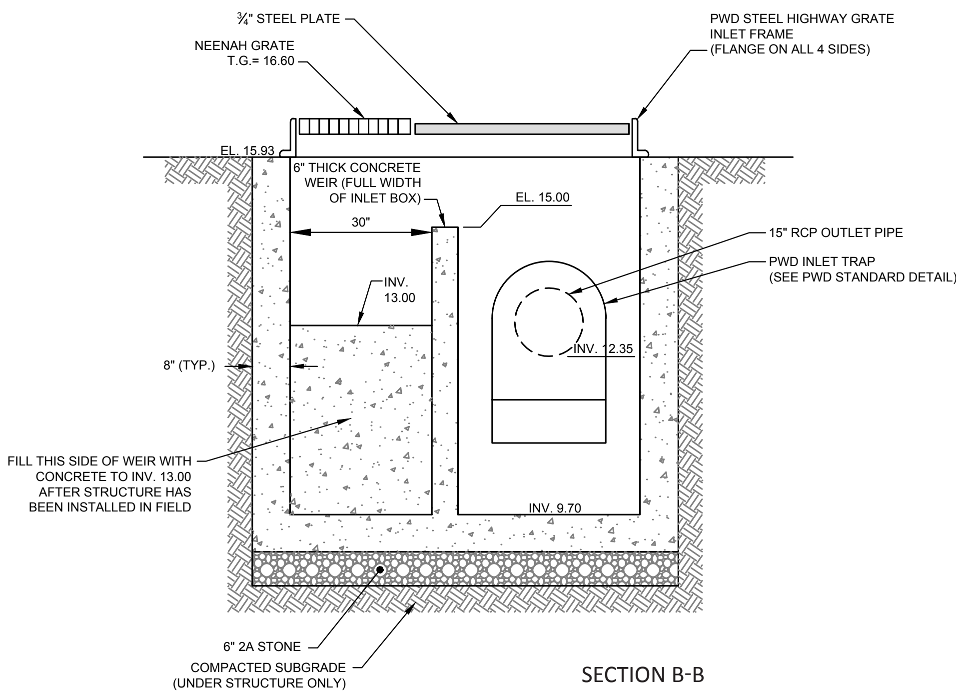


DETAIL: OUTLET CONTROL STRUCTURE AND SUBSURFACE DETENTION SYSTEM

Scale: N.T.S.



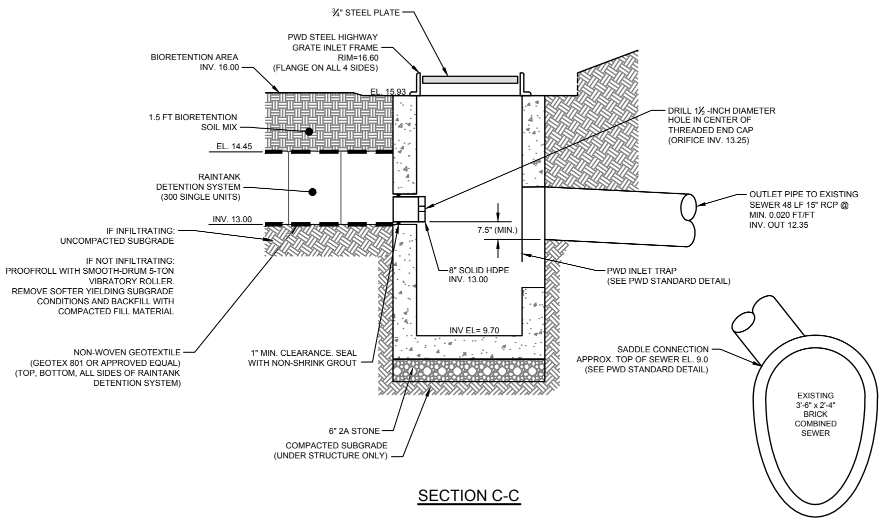
SECTION A-A



SECTION B-B

DETAILS: OUTLET CONTROL STRUCTURE AND SUBSURFACE DETENTION SYSTEM

Scale: N.T.S.

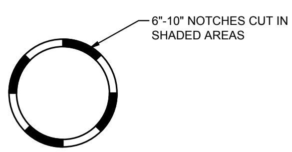


DETAIL: OUTLET CONTROL STRUCTURE AND SUBSURFACE DETENTION SYSTEM

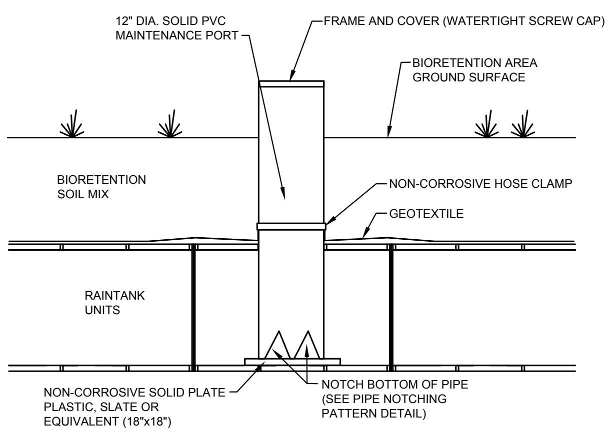
Scale: N.T.S.

MAINTENANCE PORT

THIS PORT IS USED TO PUMP WATER INTO THE SYSTEM AND RE-SUSPEND ACCUMULATED SEDIMENT SO THAT IT MAY BE PUMPED OUT. MINIMUM REQUIRED MAINTENANCE INCLUDES A QUARTERLY INSPECTION DURING THE FIRST YEAR OF OPERATION AND A YEARLY INSPECTION THEREAFTER. FLUSH AS NEEDED.

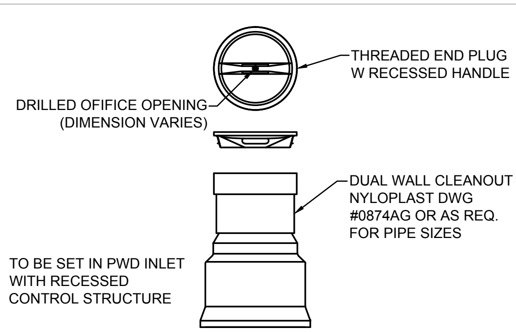


PIPE NOTCHING PATTERN DETAIL



DETAIL: RAINTANK OBSERVATION WELL/ MAINTENANCE PORT

Scale: N.T.S.



DETAIL: SLOW-RELEASE ORIFICE

Scale: N.T.S.

APPENDIX B

Stormwater Management Model

In order to simulate stormwater runoff conditions at the Penn campus, a stormwater model was created to include the study area within the Request for Proposal. The first step in setting up the stormwater model involved obtaining information from the City of Philadelphia, including public right-of-way information and the locations of the City's combined sewers. These items were incorporated into an AutoCAD drawing of the Penn campus. Drainage areas were then delineated based on blocks and likely connection points with the public sewer system. A total of 99 drainage areas were delineated. Within each drainage area, breakdowns for roof and ground level impervious, as well as pervious area coverage were determined using the AutoCAD drawing along with aerial photography. Public rights-of-way were excluded from the analysis.

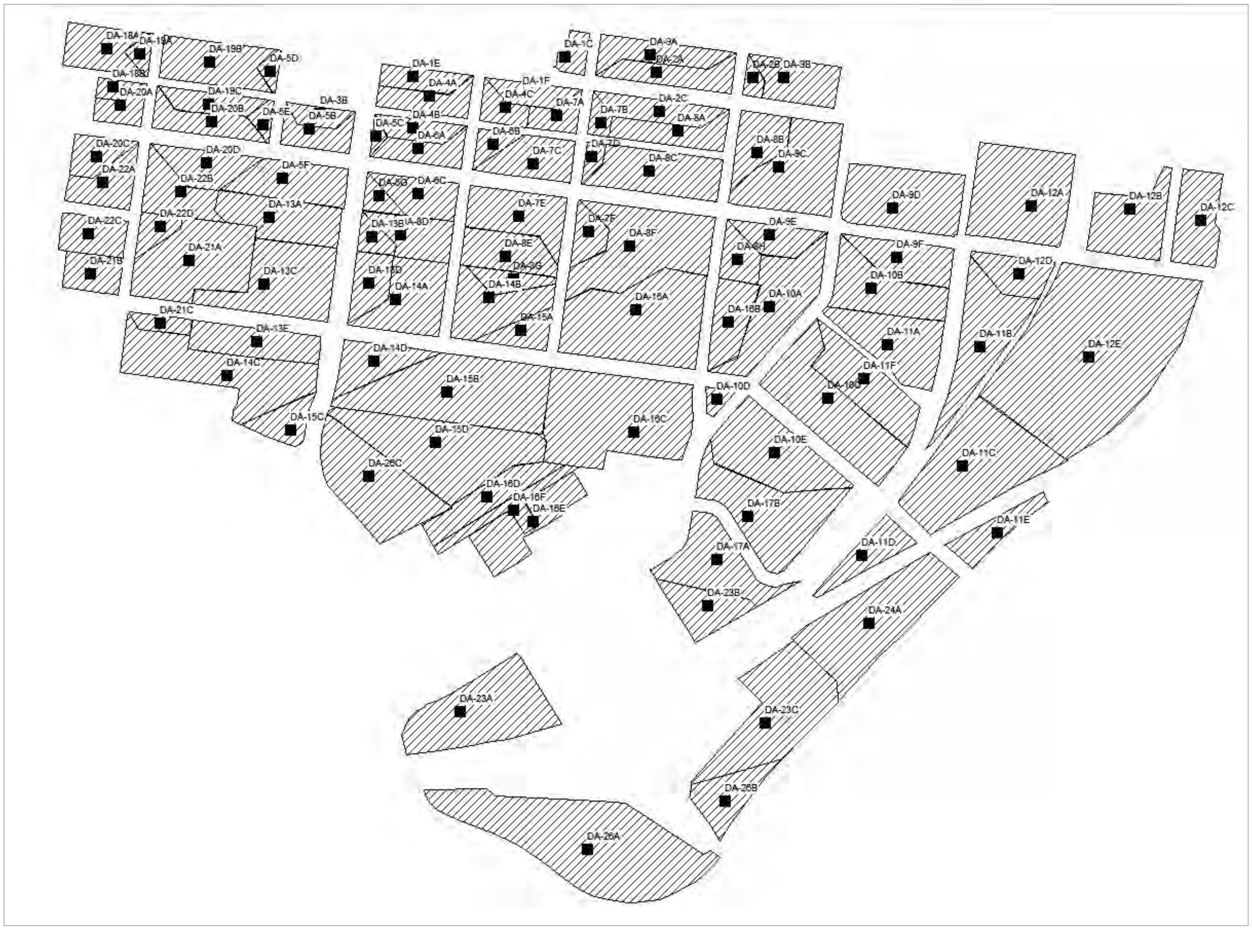
Based on the above evaluation, square footage of the existing impervious and pervious areas within the Study Area were determined, as follows:

- *Total Building Impervious Area =* *4,051,341 sf*
- *Total Ground Impervious Area =* *3,787,248 sf*
- *Total Impervious Area =* *7,838,589 sf*
- *Total Pervious Area =* *3,119,035 sf*

A breakdown of each drainage area and its corresponding coverage can be found in the Penn Drainage Area table in this section. Porous pavement and green roof areas were considered impervious in this part of the analysis.

Once the physical characteristics of the study area were determined, this information was then input into an urban hydrology and hydraulics program called Storm Water Management Model or SWMM. This software was developed by the United States Environmental Protection Agency (EPA) in 1971, and has since undergone several major upgrades. The current edition, Version 5 was used for this project. The hydrology component of SWMM examines a collection of drainage areas divided into impervious and pervious areas that receive precipitation and generates the runoff and estimated pollutant loads for these areas. The routing portion of SWMM transports this runoff through the stormwater management conveyance pipes (and channels, pumps, etc. where applicable). SWMM tracks and reports the quantity and quality of runoff generated within each subcatchment during a simulation period. Detailed information for green stormwater infrastructure, such as porous pavement, bioretention, infiltration basins, and green roofs, can be input into the program to determine their effectiveness. This program is publicly available and can be downloaded from the EPA website (http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/#Downloads).

The SWMM file in this section was set up to represent current land use conditions on campus. This model should be updated as cover conditions change and new stormwater management practices are implemented on the campus. The intent of the program is to provide a representation of the stormwater runoff on the Penn campus as it functions in connection with the City's sewer system.



SWMM Drainage area map

Drainage Area	Total DA	Building 1	Building 2	Building 3	Building 4	Building 5	Building 6	Build 7	Build 8	Build 9	Build 10	Build 11	Build 12	Total Building	Ground Imp	Total Imp
1C	31280	8818	18348											27166	4114	31280
1E	46627				2082									2082	6750	8832
1F	43988	5924	12711											18635	11084	29719
2A	74967	13814	46652											60466	8063	68529
2B	15275	6019												6019	9256	15275
2C	67156	2823	23631	12577	7300									46331	14708	61039
3B	28885	4870	1080	370	2264									8584	20054	28638
4A	57403				1791	136	514							2441	13508	15949
4B	41716	20886	12893											33779	7937	41716
4C	34656	856	6735											7591	13450	21041
5B	49873	3288	3185	2856	3535	3128	2961	2909	3389					25251	7110	32361
5C	8607	4181												4181	934	5115
5D	13892	13441												13441		13441
5E	16161	4516	2788											7304	4419	11723
5F	106267	2861	6835	4133	3812	3725								21366	32167	53533
5G	22815	18345												18345	2117	20462
6A	53896	21730	23449											45179	8717	53896
6B	25502	16910												16910	8592	25502
6C	71112	17484	7524	11301	6396									42705	26151	68856
7A	34868	24104												24104	6477	30581
7B	17849	9740												9740	6610	16350
7C	82321	65596												65596	16725	82321
7D	15373	4761												4761	6021	10782
7E	127873	16328	20689	9996	6067	5482								58562	62962	121524
7F	61179	10664	2067	2843	2419									17993	19612	37605
8A	70512	19168	12147	15447										46762	19755	66517
8B	73357	4978												4978	2361	7339
8C	139243	2331	31000	17891	45053									96275	33391	129666
8D	74630	21270	3581	6128	7723									38702	25676	64378
8E	101271	2301	3679	3383	2601	7077	5859							24900	45088	69988
8F	231938	40553	3415	16233	375	2504								63080	77043	140123
8G	37333	25284	2293											27577	4379	31956
8H	45478	4852	7003	2937										14792	9001	23793
9A	75306	21410	44024											65434	9872	75306
9B	95763	25667												25667	53610	79277
9C	180310	3807	37641											41448	29917	71365
9D	144110	16416	32313	29912										78641	51592	130233
9E	54769	11458	28021											39479	15290	54769
9F	90746	38298	14621											52919	37827	90746
10A	159955	66205	15184											81389	50724	132113
10B	130711	25575	41673											67248	46181	113429
10C	218559	1540	20370	64527										86437	113914	200351
10D	13554													0	11731	11731
10E	183742	79546	7448											86994	74857	161851
11A	172465	59508												59508	75922	135430
11B	161552	13684	57090											70774	82331	153105
11C	271489													0	118218	118218
11D	66793	746												746	11182	11928
11E	59296													0	34938	34938
11F	136032	2611	57651											60262	75770	136032

Drainage Area	Total DA	Building 1	Building 2	Building 3	Building 4	Building 5	Building 6	Build 7	Build 8	Build 9	Build 10	Build 11	Build 12	Total Building	Ground Imp	Total Imp
12A	256700	98757												98757	39609	138366
12B	99952	58287	19078											77365	22587	99952
12C	110557	56053												56053	16595	72648
12D	64264	32190												32190	32074	64264
12E	675950													0	465857	465857
13A	123267	5728	5557	2971	3437	2275	2257							22225	58337	80562
13B	25788	8988												8988	13742	22730
13C	184722	11451	2736	5060	3299	9888	48407							80841	60315	141156
13D	57237	30491												30491	21677	52168
13E	99432	3210	3806		4074	1166	21820							34076	49503	83579
14A	122342	19040	2569	3776	6494	7372	23700							62951	43878	106829
14B	127572	32587	1654											34241	51919	86160
14C	226483	2048	636	512	521	870		1200	8348	14150	32248	2628	40609	103770	94133	197903
14D	76770	39832												39832	15591	55423
15A	47187													0	0	0
15B	300660	114181												114181	134530	248711
15C	50488	19592												19592	18895	38487
15D	270304	9203	17760	94097										121060	71990	193050
16A	312448	15387	26355	25125	16532	24195	20603							128197	101347	229544
16B	77416	1985	33994											35979	22036	58015
16C	320892	221217	33540											254757	66135	320892
16D	90520	27843	19099											46942	32236	79178
16E	105901	34607	23187											57794	39050	96844
16F	52951													0	52951	52951
17A	142261	73990												73990	57332	131322
17B	205832	21525	33751	85501										140777	51463	192240
18A	79594	22294	250	1140										23684	35137	58821
18B	17110	6209	10508											16717	393	17110
19A	16830	3440	2220	1100										6760	4981	11741
19B	118942		5969	10321	2010	4723	5624	17438						46085	61266	107351
19C	49968	13586	5395	2106										21087	19185	40272
20A	36809	7013	25973											32986	3823	36809
20B	66825	2400	37860											40260	15362	55622
20C	48057	12418	14183	3860										30461	19644	50105
20D	73694		15246											15246	12874	28120
21A	205374	5648	2137	3323	6396	15143	853							33500	58537	92037
21B	54702	33859												33859	15578	49437
21C	24250	3785	2475		2811									9071	10474	19545
22A	67534	46501												46501	21033	67534
22B	81653		6587											6587	25724	32311
22C	64517	30255												30255	24408	54663
22D	32547	2754												2754	8370	11124
23A	240455	68363												68363	163395	231758
23B	78411	47594												47594	30817	78411
23C	255277	2931												2931	28838	31769
24A	255885	28039	20384											48423	17733	66156
26A	447293	36504												36504	91258	127762
26B	77728													0	7016	7016
26C	197818	21890	24456	7774										54120	49512	103632
TOTALS	10957624													4051341	3787248	7838589
														buildings	ground imp	total imp

University of Pennsylvania Drainage Areas

APPENDIX C

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APPENDIX D

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